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ABSTRACT

This volume represents the collection of papers and panel discussions of the (NASA)/University Conference held in October 1974. The purpose of this conference was to bring together representatives from universities, government, and industry to discuss and assess trends and opportunities in aeronautical engineering education with the expectation of suggesting options and directions for future programs. The conference was held in three sessions--sessions I and II being comprised of 15 papers under the headings of the State of Aeronautics and the Education of the Engineer and Technical Trends in Aeronautics. Session III consisted of three panel discussions. The topics were: (1) University/Government/Industry Relations, (2) University Research in Aeronautics, and (3) Curriculum for Modern Aeronautics. (CP)

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NASA/UNIVERSITY CONFERENCE ON AERONAUTICS

A conference held at
University of Kansas, Lawrence, Kansas,
October 23–24, 1974

Prepared at Langley Research Center

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PREFACE

The NASA/University Conference on Aeronautics was held October 23 and 24, 1974, at the University of Kansas. The participants included representatives from most University Aerospace Engineering Departments and representatives from Government and Industry.

The purpose of this conference was to bring together representatives from Universities, Industry, and Government to discuss and assess trends and opportunities in aeronautics and aeronautical engineering education with the expectation of suggesting options and directions for future programs. The conference was arranged into three sessions. The first session entitled "State of Aeronautics and the Education of the Engineer" included presentations by Government, University, and Industry representatives on the overall status of aeronautics including education and opportunities in aeronautical engineering. The second session entitled "Technical Trends in Aeronautics" included a general overview of the future of aviation and a number of selected broadly based technical discussions of current and potential future programs in aeronautics. The third session, which took place on the second day of the conference, was structured as a forum to discuss "The Role of the University in Aeronautics." The broad areas discussed in this session by three panels included University/Government/Industry Relations, University Research in Aeronautics, and Curriculum in Modern Aeronautics.

The prepared presentations of the conference are contained in these proceedings. These proceedings include all papers presented during the first two sessions, the prepared comments by the panel speakers in the third session, a summary of each panel discussion in the third session by the panel chairman, and an overall summary of the third session.

The conference program was planned under the direction of a Conference Steering Committee composed of John E. Duberg, Chairman, Langley Research Center; Alvin Seiff, Ames Research Center; Thomas L. K. Smull, Flight Research Center; Wayne D. Erickson, Langley Research Center; Robert L. Johnson, Lewis Research Center; C. Robert Nysmith, NASA Headquarters; Laurence K. Loftin, Langley Research Center; and Jan Roskam, University of Kansas. The conference arrangements were carried out by the University of Kansas Division of Continuing Education.

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SESSION I

STATE OF AERONAUTICS AND THE EDUCATION OF THE ENGINEER

AERONAUTICS IN THE AMERICAN SOCIETY

By James C. Fletcher
NASA Director

Today we are here to discuss and assess the trends in aeronautics and aeronautical education. I propose to discuss matters relating to the future roles of industry, government, and the universities in aeronautics.

America's belief in and support of aeronautics has established the United States in a position of world leadership in this field. It is a big business and is important to our country. It means jobs; it is a significant force in our economy; it is a major, positive factor in U.S. foreign trade; and it provides exceptional public transportation and military service. I believe, and I am sure you believe, that aeronautics will continue to play an important part in the future of our society.

The following facts attest to its importance to our country. In 1973, the aviation industry was responsible for producing about 12 billion dollars in military and civil hardware sales, of which about 7 billion dollars were for civil aircraft and engines. Of this, 3.8 billion dollars were in exports of transport aircraft and related equipment. This represents about a fivefold increase in civil export business in a 10-year period. Total exports of the aerospace industry, which includes both civil and military products, is expected to reach 7 billion dollars in 1974. The importance of this figure to our balance of payments is self-evident. Today U.S. designed and produced transport aircraft form about 80 percent of the world air transport fleets (excluding the Red-bloc countries). Because aviation products represent a major, positive factor in the U.S. economy and in the balance of trade, we can say that aeronautics is a "winner" -- let's keep it that way.

To further attest to the importance of aviation, the prime aircraft production plus airline industry employed some 700,000 people and grossed over 20 billion dollars this past year.

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A measure of the airplane's importance to transportation is the fact that, domestically, aircraft provide three times the revenue passenger miles of all other public transportation modes combined. The near-term growth of civil demand for air transportation has been estimated at about 6 percent per year. In this country alone in 1973, some 183 million people flew about 126 billion passenger miles. For 1973, air freight and mail,respectively, were assessed to be 2.4 million ton miles and 660 thousand ton miles. Projections for freight and mail show growth rates even higher than for passengers.

Throughout the world it is estimated that 480 million people flew 380 billion passenger miles in 1973 and the volume of air cargo was greater than 12 billion ton miles.

Military aviation, too, must be factored into our planning for the future. Nearly half of our foreign and domestic volume of aviation business is for military equipment. We must recognize and deal realistically with the military aviation business from national defense and from international trade considerations. Whether we like it or not, military equipment is a tool of international diplomacy, a deterrent to aggression.

Clearly, aeronautics is a real force in our society. It is surely one of the most significant areas of technological advancement in this century. It has directly and indirectly enhanced our way of life, -- our technical posture and the value of our goods on the international market. There is a real need to preserve our position in aeronautics.

But while the need is clear, there is also a very real danger that we will not meet this need. The danger comes from the fact that fewer and fewer young people are entering the field of aeronautics. Let me just give you one set of numbers: In 1968, 3200 students were enrolled in junior classes in aerospace engineering; in 1973 -- in the class that will be graduating next June -- there were 800.

Obviously our young people are not now challenged by a career in aeronautics. But there are challenges -- challenges which stem from the growth in demand for service, from operational, economic, and environmental factors, and from the need for judicious use of our natural resources. Social, economic, and competitive forces -- and the state-of-the-art itself -- have resulted in highly optimized and very expensive aeronautical systems.

The number of man hours for design and development, the amounts of materials, the complexity of production and test combined with worldwide inflation have driven the costs of new aircraft development to very high levels. As a result, for the military there are a few developments, and the financing of new civil aircraft developments has become very difficult. Fewer military aircraft developments coupled with divergent military and civil system requirements have reduced the flow of military technology to the civil sector. Thus, the civil sector will have to look after its own research, technology and development interests to a much greater degree than in the past.

These factors singly and in combination form a formidable, but I believe solvable, set of problems. I find them a great challenge. You must, too, or you would not be part of these proceedings.

Our position of leadership in aeronautics has evolved over a 50-year period through a dedicated industry/government/university partnership. The partnership is complex, involving education, research, technology, development, manufacturing, sales, operations, and service.

The changing nature of our internal and external national affairs has imposed stresses and changes in this vital partnership. An examination of the changing circumstances will help us assess how the partners (industry, government, and universities) have been affected and what we need to do to maintain aeronautics as a positive force in our society.

From an industrial standpoint, the changes are very clear. As I have noted, aircraft are more complex and costly in time, manpower, and money to develop. Because of the soundness of designs and the increased cost of replacement aircraft, current operational aircraft likely will be in service for times considerably greater than anticipated. Thus, we can expect to see derivatives of basic designs for the near-term future. This has led some people to refer to the coming decade as the "decade of the derivative."

Another change we must factor into our planning is that there will be a reduction in the number of military developments in future years. There is little reason to believe that this situation will change. The technology support that civil systems enjoyed in the 1950's and 1960's, as a result of military programs, is thus decreasing and is projected to decrease further because of costs for new developments and divergent design requirements. For example, future civil systems will have a different sensitivity to environmental factors, fuel conservation, and passenger service and safety.

An important additional consideration is foreign competition. It is becoming more intense. The Western Europeans, Russians, and others, directly supported by their respective governments, are building more and more extremely well engineered and sophisticated aircraft. We have current examples of this. There is active competition between the European A-300 wide-body transport and our wide-body transports and between foreign and U.S. aircraft for the short-haul markets. There is an extremely active and important competition between the French lightweight fighter and the lightweight fighters of our General Dynamics and Northrop Companies. Future market potential for this class of aircraft makes it a multi-billion dollar program.

Competition is not the only factor that has forced technological change in the commercial field. The slow awakening to social and economic needs has had significant impact. We must show a special awareness to environmental factors, noise and pollution. We must be concerned about the safety, use of resources and the adequacy of our service. Congestion of the airways and airports, all weather operations, collision avoidance, and crash safety are some of the specific concerns we must deal with effectively.

These factors, system complexity, high costs, financing, and competition, combined with the world's economic posture, have caused considerable economic stress within the industry -- stress that threatens the existence of several large industrial groups. Thus, it does not appear that we will be able to rely on industry for investments from their private funds, for activity other than that associated with growth versions of products or with the development and marketing of near-term new products having low technology risk. Yet, because of competition from foreign sources and the demand for solutions to complex social and economic problems, future aeronautical systems, to be acceptable and competitive in the open market, must incorporate the products of high risk and costly technology.

It is clear that support of the research and technology critical to the future health of civil aeronautics will depend on heavier government involvement. However, the role of industry remains paramount in the design, development, and production of civil aircraft, and promotion and operation of civil air transportation; and the design, development, and production of military aircraft.

The government's role in aeronautics has been, and I strongly believe, should continue to be the sponsorship and conduct of basic research and advanced technology programs for civil and military aviation, and the specification, development, procurement and operation of military aircraft. For civil aircraft, it is appropriate and essential that the government pursue selective significant technology to the point where the major risk for full industrial development has been reduced to some reasonable level. In addition, the government must retain the responsibility for civil air transportation policy, rules, regulation, and airway operation.

I do not foresee any change in these basic roles for industry and government. NASA will continue to play its unique role in aviation research and technology. It is committed to advancing our aeronautical state of knowledge through the provision of research and advanced technology to help us preserve a position of world leadership.

This position of leadership cannot be preserved in the face of aggressive foreign competition without advances in technology related to safety, efficiency, performance, and the environment. NASA will do its share. We will work on low-cost aircraft concepts, reducing energy requirements, reducing environmental impact; and we will continue to work on safety, aerodynamic and propulsion performance, and operations technology.

We will enhance our military support with special attention to work of value to civil aviation, and continue our support of university research with special consideration to assisting the university community in their roles of education and research in aeronautics.

More specifically, in the next five years we in NASA plan to give special attention to the following matters:

1. Engine and aircraft technology, tending to designs that conserve energy and provide effective service.
2. Technology to utilize fuels such as hydrogen, in order to reduce reliance on petroleum-based fuels.
3. The technology required to design environmentally acceptable aircraft from noise and pollution considerations.
4. Advanced avionic systems for both navigation and aircraft flight control to improve safety, comfort, and reduce congestion.
5. Low-weight, high strength, non-strategic structural materials and design methods, to reduce the demand for expensive, energy intensive short supply materials and to reduce weight and improve operating efficiencies of engines and aircraft.
6. Close cooperation, including joint programs, with the Department of Defense to enhance both our military posture and the general state of knowledge for civil applications.

NASA, through the years, has worked closely with the university community on training programs, grants for research and technology, and contracts for research and technology. In fiscal year 1972, our university program totaled some 1,600 grants and contracts with a value of some 100 million dollars. Of this, about 200 grants and contracts, with a value of about 10 million dollars, were in aeronautics. We have been slowly increasing our support in aeronautics. This trend will continue. We propose to assess what we have done in this arena and examine ways and means to further the productivity of this core activity.

We in NASA have not stopped examining the way we do business. Two matters currently are of particular concern to us: a good insight into the future scope and direction of our aeronautical activity to help focus program decisions for the next 4 to 5 years, and an examination of the way we conduct our affairs with a view toward strengthening our university and industry relationships.

To assist us in developing our future program, we have organized a government long-range study group to evaluate the "Outlook for Aeronautics" in the 1980-2000 time period. This study group has been working with industry representatives to gain as much insight as possible into this complex question. A report will be developed which we believe will provide all of us with a thoughtful document that will assist in building our future aeronautics programs. This report should be available in the summer of 1975.

I have noted that our success in aeronautics can be traced to a strong, unique aeronautical research and technology capability that resulted from a productive industry/government/university working relationship. There is an inherent danger in taking this relationship for granted.

We propose to pursue the matter of strengthening our relationships with the universities, industry, and other government agencies through special discussions. We have a start on the process at this conference. I invite your comments on the government's and NASA's future role in aeronautics, and on ways to strengthen NASA's relationship with all of you in industry, government, and the universities in your round-table discussions.

The basic strength of our aeronautics activity stems from a strong science and engineering educational base. As I said earlier, the fact that university enrollments in the engineering arts and sciences have been declining is a matter of serious concern. This trend needs to be sharply reversed.

The future of aviation in this country depends on maintaining a high quality university program which will attract and educate the individuals who will be the aeronautical researchers, designers and developers of the future, and who will perform the high-level basic research that forms the very foundation of our complex aeronautical technology. This is vital to the future health of our aeronautics activity. Government and industry cannot move forward without good people. This job rests on the shoulders of all of us -- the university community, government, and industry. Success will help ensure that aviation remains a vital productive part of our economy and society.

To be successful in bringing the right kinds and numbers of bright, imaginative, productive young people into the field, we must communicate to the new student that there is work to be done of social and economic significance which can impact in a positive way our quality of life; that the work is challenging and rewarding; that there are jobs and a future in the broad field of aeronautics; and that special talents are needed to sustain our position of world leadership in aeronautics. Clearly, the first step is to establish credible goals and to convince the prospective students that these goals are worth the investment of their time and the dedication of their lives.

Let me propose one such goal: to provide the technology needed to produce aircraft fuel savings of 50% within the next 20 years. Since jet fuel today amounts to 8% of the United States petroleum consumption, and will amount to 12-15% by 1985, a 50% reduction in aviation fuel usage is a most worthy objective.

I am convinced that the goal can be reached. It will require work on advanced materials and composite structures to reduce weight; on avionic systems such as fly-by-wire and active controls for further weight reductions; on "supercritical" aerodynamics and boundary layer control to reduce drag; on advanced engine cycles to reduce fuel consumption; and on operational techniques to reduce air traffic delays.

NASA today is working in all of these areas, and many more. We are working on airfoils and wing fuselage combinations that will significantly increase the efficiency of aircraft; on new aircraft concepts for improved high density short-haul transportation; on quieter, cleaner, more efficient engines; on new kinds of fuels and engines so that we may not have to depend on hydrocarbon based fuels; on new materials and structural concepts for more efficient design; and, of course, on the technology that will support the development of practical supersonic air transportation.

A combination of talents and capabilities in the field of research, technology, engineering, marketing, and finance to remain competitive in aeronautics will continue to be necessary. But, of fundamental importance is the need for a sound research and technology base. Without the new young people, the better ideas, and the better designs and techniques for implementation and production, we will not be able to remain successful in competing with other countries.

In summary, then, I believe that we have challenging times ahead. We have and will experience in the future intensified competition from overseas. Military programs can be expected to reduce in number and in their technical contribution to civil aviation. In large part, civil aviation will be expected to support its own research and technology needs. But its ability to borrow or attract needed capital will prove difficult. Therefore, an aggressive government research and technology program is important to the continued health of our aeronautical activity. NASA is prepared to make an important contribution in this direction.

There are many problems to be solved today. They are not easy of solution and the problems we see for future developments are even more difficult. The improved service and growth of aviation depends on solution to these problems. I am confident that the problems will be solved by application of energy, intellect, and adequate support. An integral part of the resolution on these problems and preservation of a dominant role in aeronautics is the strengthening of our institutional relationships, and the revitalization of our educational base. More than ever before, the role of the university is important.

Key to the structuring of a proper aeronautics program is the astute delineation of future aeronautical goals and program objectives and plans. NASA or, for that matter, the government cannot do all of this alone. Proper action will require working partnerships with industry and the university community. We in NASA are dedicated to aeronautics -- to finding better ways to do our part of the job. NASA is prepared to support a stronger aeronautics research and technology effort. We need your help in maintaining the required strong posture for aeronautics. We are convinced that firm action is required, that we have the tools for the job, and that the redefinition of the tasks and ways for their accomplishment can start here. We ask you to join us in this important job.

Collectively, we need to maintain our aeronautics superiority in the face of difficult challenges. This requires renewed dedication.

We need to strengthen our industry/government/university relationship and seek better ways to maintain our nation's vigor in aeronautics.

We need to define and articulate the challenges and importance of aeronautics to the youth of the country. Through proper and adequate communication and support, we can reprime the intellectual source of the strength of our programs -- the college graduate.

For NASA's part, we are dedicated to vigorous pursuit of these objectives and will work diligently with our partners in industry, with the other government agencies, and with the university community to achieve success.

SOME DEVELOPING CONCEPTS OF ENGINEERING EDUCATION

By Courtland D. Perkins
Princeton University

PREFACE

Of all the great government agencies, the NASA has had the deepest commitment to the care and feeding of the technical programs of this country's universities. The NACA, and then the NASA, has always recognized that faculties and their graduate students are the source of many new ideas, but they have been sensitive to a more fundamental point, they have felt a responsibility to motivate our best young minds towards the problems of modern technology. They have always done this to the limit of their financial resources. Before World War II the NACA was involved in many university research programs and made it possible, through open conferences, for faculties to keep abreast of the rapidly advancing fields. Their great competence and world stature made them a shining goal for our ablest graduate students, and many joined this remarkable organization on graduation.

After World War II, and as NACA became NASA, this love affair with universities continued, particularly so during the great Apollo buildup. The NASA never forgot that the young students and the faculties in our technical programs were at the heart of continued national competence. They spun off many millions of dollars to fund fellowships, grants, facilities and general support programs. As the NASA budget receded, a great deal of this support had to be withdrawn, but the impact of this sophisticated university support program is still being felt.

Today the NASA continues to be concerned with supporting university technical programs and is sponsoring research along many lines and with many institutions. The fact that they are sponsoring this university conference here today gives credence to my point that NASA feels a national responsibility for certain technologies, and that the motivation and education of our best young minds are of crucial importance to their success in the long run.

We are, of course, privileged to be invited here by our able colleagues from the University of Kansas and are most grateful to them for hosting this important and timely conference.

I have been asked to address my remarks today to the problem of Engineering Education in the large. The following speakers will sharpen their focus to Aeronautical Engineerihg education and then to the future of the particular technology under review, that of Aeronautics.

INTRODUCTION

Engineering and engineering education are trying to achieve some sort of normalcy after experiencing a breathtaking buildup between World War II and 1970, leading to what I like to refer to as the Golden Age of high technology and graduate engineering education. This was followed by an explosive decompression that turned this gold to lead, altered motivations, opportunities, and created very real financial difficulties in industry as well as educational institutions.

The fields of science and technology were accelerated exponentially during the 50's and 60's due to the establishment of national goals that required the highest technology development. These goals enjoyed top national priority and almost unlimited funding. Two of these goals were the crash development of ballistic missiles and the national space program focused by the great Apollo lunar objective.

The emphasis during this entire period was on higher and higher technology generating an overwhelming demand for highly educated engineers. This demand came from industry and government organizations with a strong emphasis on Ph.D.'s.

Industry found that to compete successfully they had to be able to indentify a large and highly skilled staff ready to take on the most complex jobs. They set about acquiring a posture of great sophistication by developing basic research laboratories with more of a public relations rationale than anything else. Many had little or no relationship to their end products.

All of this put pressure on our universities to organize or to accelerate graduate education programs, increasing further the demand for highly educated graduate students to join the mushrooming faculties in science and technology.

The national goals were easy to identify and to relate to the young graduate who could look forward to exciting and highly paid jobs. The universities' expanded graduate operations were being paid for through ever increasing government sponsored research programs and through the rapid expansion of available government sponsored fellowships. Programs such as NASA university support programs of the 60's and the DOD's START program helped encourage universities to expand their programs to fit the ever increasing demand of the starry eyed young student. This then was the Golden Age.

The Golden Age was funded by our crash programs with the major motivation being essentially fear. Fear of a missile gap in the mid 50's and of a space gap in the late 50's. By the end of the 60's all elements of our technical society was badly over expanded - and as is usual under such circumstances a serious collapse followed. We are just now digging out from the debris and searching for some sort of normalcy.

By the end of the 1960's our great Apollo goal had been brilliantly achieved, but it soon became apparent that there would be no follow-up to this great spectacular. At the same time our crash programs in ballistic missiles had developed to a point where most military thinkers felt that real deterrents had been achieved. We might say that the missile gap was either closed, or found not to exist by 1965, and the space gap had been more than eliminated when we sent Armstrong and friends to the moon and got them back safely in 1969. As I have mentioned, it was national fear that powered most of this program during the Golden Age and these fears were eliminated by 1970. Besides the elimination of the "gap" motivation, the Vietnam war came to a sharp focus by

1970, and many factors in our attempts to disengage brought on the great protesting on our campuses and elsewhere, putting further damping on the euphoria of the previous years. Students somehow related our Vietnam experience to the high technology accomplishments of the 50's and 60's. If high technology was the hero between the end of World War II and 1970, it was viewed as the villain in the early 70's. Science and technology was deemphasized with a great rush. Our over expanded industries cut out large fractions of their bloated staffs and for a time ended their demand for graduate students. Many universities were left with their over expanded facilities and faculties and had to face reductions in their sponsored research programs, available fellowships, and a rapid decay in student demand. They were far out on the limb.

The young technically or scientifically oriented person of the new era then could not look forward to an assured future. In point of fact, it was hard for him to identify what jobs might be available when he graduated from school. He was more or less turned off by high technology and there was a rapid shift of concern towards more societal aspects of engineering activity. The motivations of young students towards engineering became less clear and few related to the major hardware programs of the day. Industry, and in particular, the aerospace industry, suffered the same severe contraction, eliminating an immediate demand for graduate students and making careers along these lines of dubious interest to students. Contact between industry and the universities was largely lost.

Programs today are becoming very social and software oriented. There is a growing concern that we are not doing a good job in interesting young students towards major high technology programs and developing a young generation of highly competent and innovative engineers.

This conference is pointing up one such technology area. In spite of all this, I would like to make the point that the potentials for young students with a modern engineering education are expanding rapidly to cover many new areas of interest and careers. This news is just now getting the attention it deserves, and we are seeing a buildup of undergraduate demand that will expand more rapidly in the future.

WHERE WE ARE TODAY

After first experiencing the great technical golden age and then living through the subsequent collapse, the engineering schools have to recognize and face up to the real world of today. The present facts of life are:

a. We are experiencing a recovery in the number of undergraduate students in our engineering schools, but their motivations are changing drastically.

b. There is a fall-off in interest in high technology hardware programs and an increase in interest with engineering related to the problems of society. Engineering undergraduate programs that deal with the environment, transportation, bioengineering, and energy are thriving.

c. Undergraduate engineering education continues to shift towards breadth and towards engineering science. These programs are preparing our young students for broad career possibilities. It is interesting that an undergraduate engineering program is having high acceptance for entrance into major professional schools in law, business, government, and medicine.

d. Although undergraduate education enrollments seem to be expanding, graduate programs are not. There seem to be many reasons for this, including fewer graduating undergraduates, a dearth of fellowships, fall-off in sponsored research programs, and shift of interest towards non technical graduate programs.

e. Many graduate programs, however, have more support funds available than adequate U.S. applicants. This has led to a large increase in the number of foreign students.

f. After the large cutback by industry, few new graduates were hired for quite a few years. There are now too few young engineers in many of out major technology industries. This lack is now being recognized and there seems to be a slow increase in demand for highly motivated and intelligent young graduates. The supply, however, has eroded badly and is continuing to erode. Our best young minds are looking elsewhere.

g. Our faculty competence has moved towards more scientific and applied mathematics interests, with little background in the real world of engineering hardware development. They are not generating much interest in their small number of graduate students towards programs of interest to industry.

h. I want to emphasize again that the scope of career possibilities in engineering is broader and deeper than ever before. It is still an exciting and rewarding field now expanded to pick up Engineering or Applied Science and Applied Mathematics on the one hand through technologies to hardware items and finally to new systems. The potential demand for innovative young students with engineering backgrounds is very large indeed.

MOTIVATIONS OF ENGINEERING STUDENTS

We are seeing at Princeton a rapid rise in the number of undergraduate students enrolled in our engineering undergraduate programs. In fact, this fall's entering class is the largest in our history and perhaps one of our best. The average SAT for this new class is 730, indicating that some of the best young people are choosing engineering for their undergraduate concentration. The question is why are we seeing this new trend, what is motivating the young student towards engineering, and what sort of a career are they looking forward to. Any study of this new generation of students will rapidly show that many are motivated by entirely new factors that just didn't exist in the recent past.

Not too many years ago, young engineering students looked forward to careers related to various hardware entities that shaped their educational goals. I was typical of this generation. My interest in aeronautics started when at the age of three, I was given an airplane kiddie car. I just knew from then on that I was going to be involved with the aeronautical scene in some form. Others of my generation built themselves crystal set radios and had earphones clamped to their heads nightly. From this base came their interest in electrical devices. Most of the engineering students of this era related to some hardware entity and knew what his future career might be.

The undergraduates entering our engineering programs today are normally not as simply motivated as this. There are still some who want to build or fly airplanes, develop radars, lasers and computers, but they now comprise a smaller percentage of the total undergraduate engineering body. A large number have only vague concepts of their future careers but are attracted to interdepartmental programs in environmental protection, urban transportation, bioengineering, and energy resources.

Another strong motivation for enrolling in undergraduate engineering comes from the growing realization that these demanding programs are becoming excellent background for entry into the major professional schools in law, business, medicine, and government. The large majority of engineering undergraduates are looking forward to graduate school, but only a small percentage of these are being attracted to graduate programs in high technology. Many of these students have become afraid of industry as the job potential has eroded badly over the past few years. This is particularly true of the aerospace industry. Our very best students are being attracted to the engineering-society programs or to the other professions accentuating the problem of developing young, highly motivated students for industry.

All of this presents a problem to the normal departmental structure of our engineering schools. There must be flexibility in these organizations to adjust to these new interests. This is not any easy thing to accomplish as our departments have become very protective of their programs, have problems with their engineering societies, and even the ECPD. Engineering will always keep shifting its focus onto the problems of the real world, and by one strategy or another we must adjust to this.

The problems of our graduate programs in engineering are more complicated than those of our undergraduate. Again this is more difficult for aeronautical or astronautical programs which have been the hardest hit. The demand for graduate engineering education has fallen off due to many factors. The loss of major government agency fellowship programs, the drop-off in undergraduate population, the end of the draft, the lack of demand for graduate students by industry, and the general apathy with high technology that has characterized these past few years. Many of our technical departments still have healthy sponsored research programs and assistantships available. Unfortunately our top students are looking elsewhere and many are having difficulty filling available slots. Some schools are solving the problem by increasing the admissions of foreign graduate students, of which there are many applicants. We worry about the increasing percentage of foreign nationals in our graduate programs and wonder if there should be some limit to this.

Many of our graduate students are not being motivated towards real innovative thinking or excited by faculties who lead them in these directions. During the golden age, our rapid expansion in faculty resulted in a shift of interest towards engineering science and software with a vanishing interconnect with industry and their problems. The inventor or engineer who will dare to try something new seems to have a hopeless feeling that everything possible has been thought of, and there is nothing new to look forward to in the immediate future. It is nearly impossible to teach young people to be innovative, but it certainly excites young students to think originally if they are working closely with a faculty man who is breaking into new areas.

I was a student of Dr. Stark Draper at M.I.T. about 1940 when he was at the peak of his great innovative career. I can still remember the first lecture I attended in his graduate course. He arrived in shirt sleeves, green eyeshade, obviously had been up all night, and accompanied by two assistants similarly attired. He introduced his lecture by saying "Gentlemen, I will lecture to you this morning on what we discovered last night." This was heady stuff and a thrilling experience for his students. He encouraged his young colleagues to think originally and daringly - and many of them did.

At that time there were many other powerful innovators on our engineering faculties. At M.I.T. we had DeForrest, DenHartog, Gordon Brown, and many others. They combined sound scientific background with the desire to be creative and break into new fields. They could make things work. There were many others of similar capabilities at other schools and they helped develop the highly productive generation that followed immediately on World War II.

My biggest worry today is that we are becoming too specialized - too science and software oriented - with few getting their hands dirty on developing new things. We just don't seem to be producing new Drapers, DeForrests and Browns. One reasons for this is that there has been a loss of contact between universities and industry, and this is becoming a real concern. What is needed is a clear signal from industry that they are interested in engineers educated to the graduate level, that they take more time to see that adequate programs are available, and that faculties with adequate engineering backgrounds are represented on the faculties. In this new environment, what are industries' real interests?

Last year I chaired an Air Force review team on the status of propulsion technology. Much to our astonishment we found few, if any, young engineers between the ages of 22 and 30 on the staffs of our engine development companies. When industry tried to fix this, they found very few graduate programs in the general field of propulsion technology with the numbers of faculty and graduate students active in these areas dwindling towards zero.

We need renewed industry interest in graduate education programs and help from government laboratories to see that exciting and innovative research programs are reestablished. We need to remotivate young faculty and their graduate students along these lines. When this is done, I believe we will see a strong recovery in our graduate engineering programs.

An interesting aspect of this is that although we may be concerned with the dearth of new innovative programs, there is no dearth of evolutionary expanding technologies. In point of fact, we have many more technical potentials today than society has a need for. In the aeronautical field, for example, we have made evolutionary developments in aerodynamics, structures and propulsion to a point where we can do many things only dreamed of less than a decade ago. We have the technology to develop supersonic transports. We can develop short haul V/STOL transports. We can build large capacity tankers and can even provide nuclear propulsion for aircraft. So far neither the civilian or military sectors see a sure payoff from such systems.

In space we have the same situation. We have the technology to do many things that we just aren't doing because the rationale for their use is just not viable. In both cases the greatest advocates of these systems are the engineers themselves.

General Otto Glasser put this very neatly some years ago when he said that the engineers are pushing on wet noodles and no one is sucking on them.

The modern engineer must be able to relate his new potential to the solution to a real world problem. If he is to make a real contribution, he must be able to think of his bright new idea in terms of systems with real payoffs. Those who can do this will be the most successful in the future.

CONCLUSIONS

After the great expansion in engineering education that I refer to as the Golden Age and the rapid contraction that followed, engineering is today striving to recover a position that might be stable for the next few years. I believe we have new patterns emerging for our undergraduate programs, but the future of many graduate programs is still unsure.

At the undergraduate level, we are experiencing a recovery in demand, with engineering programs being sought for different reasons and for different motivations than heretofore. A great many undergraduates are interested in the societal aspects of engineering and are populating programs in environmental protection, urban transportation, energy resources and bioengineering. Undergraduates are also enrolling in engineering as they are finding that such curricula are excellent background for entrance into professional schools in business, law and medicine.

The high technology or hardware interests of our engineering undergraduates are recovering slowly. The effects of the great decompression around 1970 are still being felt as undergraduates are still concerned over job demand and are still somewhat turned off on such programs. Nonetheless there is a growing industry demand for young innovative engineers, and this will impact these programs in the very near future. In spite of our great and important concern today on engineering societal programs, the largest demand will come from industry which has let their engineering staffs get older each year without an adequate influx of young minds.

Engineering has great potential for the future and at the undergraduate levels is recovering and may well build up more rapidly in the future. The engineering faculties have the problem of orienting to the societal problems of today, while at the same time leading the undergraduates into expanding interests in high technology hardware programs. To do this, of course, we have to have faculties who have these interests and capabilities - unfortunately with our system of built in obsolescence (tenure) and with the universities in difficult financial straits, it is very difficult to move a faculty's capabilities as fast as the real world scene changes.

The engineering faculty then must adjust to recognizing new undergraduate interests and motivations and realize that their graduates have taken engineering for many purposes not well aligned with the standard engineering department expertise. It's a great challenge to these faculties but it presents them with new opportunities for playing a more significant role in the future.

An undergraduate engineering program is a demanding one that requires considerable discipline and motivation for a young undergraduate to face up to, particularly if he is in a liberal arts university with his colleagues involved in programs considerably less difficult and with less requirement on his time. Engineering education is a real educational experience putting the undergraduate over mental hurdles that really develop his mind. It is this aspect I believe that attracts the major professional schools to graduates of engineering curricula.

At the graduate level the situation is still unclear for the future. The deterioration in demand for graduate engineering education that followed the collapse from the Golden Age has been arrested but recovery will be slow. Those things that were at the heart of the golden age just have largely disappeared and are not recovering very fast. The loss in fellowship support, the fall-off in government support of research, the unclear view of future job possibilities, and the end of the draft all have made a major recovery difficult.

Again let me repeat, what is needed is a clear signal from industry and government that they are interested in engineering education to the graduate level, and that they take the initiative to see that research programs in universities develop the highly motivated and innovative young engineers of crucial importance to our national competence.

I believe that the NASA understands this very well and always has. Graduate programs in engineering not only produce bright new ideas, valuable in their own right, but provide the motivation of young students towards interest in important new technologies.

The care and feeding of the technology of aeronautics through sophisticated interconnect with technical programs in universities is a prime NASA concern. The existence of this conference proves this point. We need now similar support from industry and other government organizations to attract students and faculties to areas of real national concern.

RECOMMENDATIONS

1. First of all, we must get the message out that careers in engineering are exciting and rewarding, and that career potentials have expanded along new lines. This plus the fact that new interest in recruiting young engineers by industry is creating a healthy and growing demand.

2. It is important for industry to pay more attention to engineering

programs in universities. Industry must help insure that such programs are focused on the problem of the real world and that the faculties of our engineering programs have their interests at heart.

3. The government organizations responsible for various technologies must recognize that the motivation and education of young graduate students is one of their responsibilities. They should see to it that faculties and their graduate students have sufficient support to insure not only a flow of new ideas, but also a flow of our best young men for concentration on these problems.

A good example of such support is a recent directive from the Secretary of the Air Force, Dr. John McLucas, to the Air Staff. The directive is dated October 10, 1974. In this order Dr. McLucas orders that Air Force research be protected from large systems cost problems, and further that

> "The primary emphasis of Air Force research should be preservation and enhancement of university capability to provide insight into the basic sciences and to train students in those scientific disciplines critical to the Air Force."

and "Further, I desire that the emphasis of Air Force basic research be shifted at a reasonable pace from predominantly support of Air Force in house activities to predominantly outside university support."

In other words, he is directing that the DOD 6.1 funds be focused on university research and not spent in house laboratories.

This directive indicates that the Air Force understands the problem almost as well as does the NASA. We now need more sophisticated industry involvement to round out this picture.

I would like to repeat my opening remarks. Of all the government agencies involved with large programs of research, the NASA has been consistently concerned with the output of our university programs. They have been a strong influence on these affairs for many years. That they are sponsoring this conference is proof of this.

I believe that with this support, plus that which will come from the Armed Services, plus a refocusing of interest by industry, we will again reestablish engineering as the great and exciting field for our best young minds.

CURRENT AND FUTURE OPPORTUNITIES IN AERONAUTICAL ENGINEERING

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ABSTRACT

Current demand for Aeronautical Engineers is approximately balanced with supply, with some shortfall in certain specialties. In the near term (5 years), demand will exceed supply of new graduates. A number of factors have brought on the state of imbalance: the cyclic nature of the demand of our defense requirements; drastic changes in DOD aircraft procurement; the emergence of the Space Age; evolution of social attitudes toward technology with resultant decline in enrollments; and the universities themselves through their influences in the direction of careers selected by engineers. These factors have been counteracted somewhat by increased DOD emphasis on aircraft development programs but more importantly by the favorable growth in civil aircraft requirements. The future outlook for Aeronautical Engineers is bright. In fact, a concerted effort is required to bring the supply up to the demand. To correct the imbalance requires a conscious, coordinated program supported by industry, government and educators.

INTRODUCTION

Fellow attendees, it is a pleasure to meet with you as aerospace representatives of industry, government, and universities, to discuss the future for aeronautical engineers.

In a relatively short period of time this profession has lost favor with engineering students at an alarming rate, and engineering in general is failing to attract students as it once did. If we do not change these trends they will have significance at both national and international levels. Our responsibilities are real. Society demands much and we must make our profession competitive.

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*Presented by R. Fitzsimmons.

STATUS re AERONAUTICAL ENGINEERING

From earliest time, man has been challenged by the idea he could fly. Greek mythology had Icarus; the Italians, daVinci. Every generation addressed this challenge of man to fly. Today's youth are following Lilienthal's interests of a hundred years ago on hang gliders using developments accomplished at NASA by Dr. Rogallo.

The Wright brothers, acting in an excellent demonstration of the scientific process at work, gave us a powered flight vehicle, and aeronautical engineering was on its way.

Lindberg, in 1927, sparked the imagination of millions and accelerated public acceptance of air as a form of transportation.

Consistent with the expansive growth of aviation in our national way of life, there was an increasing demand for aeronautical engineers continuing through the early 1960's, see Figure 1. The buildup in space activities increased this growth rate as professional degrees in aerospace and astronautical engineering were added. This increase continued until the aerospace slowdown of 1969-1970 caused a sharp reduction in enrollments. Low enrollments now enable accurate projections of further declines through 1976. We can ill afford the supply of future professionals to be so small.

The regression trend since 1970 in the number of students taking engineering (-21 percent) or aerospace engineering in particular (-63 percent) stands in sharp contrast to the growth in other fields of higher education. This is unfortunate as at no time in history have there been so many social problems to solve requiring technically trained individuals.

Why take engineering? We need the quantitive thinking of the engineer who is trained to establish a value system leading to professional decision making. It is essential for complex problems requiring technical competence and methodical preparation. As such, engineers become well equipped to follow many careers where good management practices are a dominant prerequisite.

Historically, there has been an apparent consistent relationship between length of schooling and subsequent professional growth. As we look at trends we are nonetheless heartened by the quality of the future aerospace engineer. Where only 26 percent of the aerospace graduates in 1970 had advanced degrees, we can now anticipate 62 percent will be so equipped by 1976.

Graduates look forward to progressive improvement in their occupational status: what they do, how they do it, and what the responsibilities and financial and social rewards are to be. Obviously, as recent adverse publicity on aerospace employment opportunities became widespread, those students interested in careers in aerospace must have taken stock. They have been willing to make a higher investment in education than their predecessors and more have gone on to earn M.S. or Ph.D degrees.

We welcome this advanced education in the aerospace graduate. However, we are disturbed about the reductions in quantity of graduates as we view our needs to meet our expanding opportunities over the next several decades.

We have a challenge ahead of us. Educators and leaders in government and industry need to devote the time and effort necessary to reverse this declining interest in aerospace engineering careers or it bodes future ills for our industry and for our nation.

Our industry needs new aeronautical engineering graduates. Half of the aerospace industry engineers are necessary to support active production programs, some of which are expanding. The other half are required for the increased emphasis on research and development projects. Military aircraft R&D are taking an increasing share of the DOD sales dollar. The market for civil aircraft is expanding and the military side seems to be starting back up. No one really knows the future, but the signs appear solid enough to predict that the future demand for aeronautical engineers looks bright, from the students' point of view.

BACKGROUND

Four wars have been the accelerators for aviation developments, starting with World War I and carrying through Vietnam, see Figure 2. The massive efforts taxed every engineer available. It is difficult to remember that we actually built one airplane per hour at Douglas during World War II.

Following World War II, a spurt in the number of civil transports manufactured laid the foundation of the world air transportation system we know today.

It is only recently, however, that civil transport dollar sales value has come up to the level of U.S. military aircraft sales, see Figure 3. This is significant to a young person in college. For the first time aeronautical engineering careers can be dependent more on civil markets than on the military. This is healthy as our nation's efforts shift from war to peace and as our federal expenditures move from national defense to human resources, see Figure 4.

It was unfortunate that the manned space tasks and the military aircraft and missile programs passed their peaks at times when civil transport efforts were unable to absorb the surplused work force and the serious aerospace unemployment problems of 1970 arose, see Figure 5. A careful look at the total aerospace industry sales, see Figure 6, from 1965 to the peak in 1968 shows that the rapid buildup was predominately due to aircraft sales. The large decline in 1969, 1970 and 1971 also can be readily traced to the large decrease in aircraft sales on top of the reduction in the NASA space program. This decline would have continued had it not been for increases in aircraft deliveries in 1972 and on. We as government and industry leaders must assume at least part of the responsibility for large ups and downs in our business. We might have been able to plan our efforts better, but then all Monday morning quarterbacks perform better than the man on the field on Saturday.

Actually, the government did something about aerospace unemployment. Many new aircraft programs were initiated, especially in new military prototype demonstrators. Mistakenly, we failed to communicate these positive actions publicly. We failed to tell the educators that our requirements for aeronautical engineers were increasing. We failed to communicate the same ideas to potential students. Obviously, we have done a disservice to that bright student who could have been challenged by aeronautics, but who went elsewhere because of the bad publicity our industry allowed to go unchallenged. No one was portraying exciting rewards for our profession. The publications were citing case histories of aerospace engineers unemployed or in underemployed jobs, and we did nothing to portray the exciting rewards of our profession.

It is my belief that the aircraft industry allowed itself to indulge in self-pity and became vulnerable to attack by anti-technologists and headline seeking individuals. When we overextended our industry in 1968, we had some unqualified people employed. The reductions in employment that followed were severe, with many good engineers released. But it was nowhere as critical for the aeronautical engineer as described in the press in 1970. A recent survey of aerospace workers taken before and after the 1970 layoffs shows that it was the poor performer who went first. Layoffs were 10 times as prevalent for engineers whose performance rating was in the bottom decile as compared to those in the top 10 percentile.

Where were the headlines or articles reporting that the unemployment rate for engineers was back to a characteristically low 0.8 of one percent early in 1973? Engineers were busy addressing new research and development projects.

RESEARCH AND DEVELOPMENT TRENDS

Today, in aeronautics we are now capitalizing on the R&D accomplished through 1970. Once again we have become an industry with growth ahead and are competing well on an international scale. We have every expectation to retain the U.S. as a leader in aviation, second to none. As of June 1973, 94 percent of the free world's civil transports in service or on order are U.S. made. Possible, we will face short-term disadvantages should the Concorde prove to be highly appealing to the passenger, but we are trying hard to minimize such losses of leadership.

Outlays for aeronautical research are a significant part of our total federal research and development effort, see Figure 7. Within this federal aeronautics effort we see simultaneous development of two military transport demonstrators (YC-14 and YC-15) to explore aeronautical concepts offering military and commercial possibilities, see Figure 8. Whole new concepts of transportation could result because of the new technologies being developed including revolutionary improvements in community noise.

There is continuing development of the F-15 Air Force air superiority fighter and the Navy F-14 long-range carrier-based fighter. The U.S. also has competing developments underway on the new air combat lightweight fighters, the YF-16 and YF-17. Such competitions are healthy and assure our nation of the most viable aircraft to satisfy military requirements. There are others, e.g., the Heavy Lift Helicopter, AWACS, close air support gunships, etc. The list is surprisingly long.

The strategic forces buildup that started in 1952 now sees us with an inventory of bombers and tankers that by aircraft standards are old: 16 to 20 years. The best way to update this third option of the TRIAD, which has so successfully helped forestall a World War III, remains to be accomplished. A bomber concept is under development; others are envisioned. A series of tanker concepts are under consideration. New relationships may be required between manned and unmanned, low altitude or high altitude, bomber or missile carrier, drone or single carrier, and high speed versus penetrability for the next strategic force requirement. Even cryogenic fuels such as liquid methane or hydrogen lie in our future as does nuclear energy. Just how or when is not clear, but as a result of the Middle East control over fuel last fall, these new energy sources are now certain to demand careful attention - sooner than we envisioned.

In addition to the military developments, industry is developing new so-called "10-Ton" engines both here and abroad. There are competitive developments of the large civil engines, the CF-6, the JT9, and the RB-211 for the new stretch or cargo versions of the DC-10's, 747's and L-1011's.

The criticality of aeronautical R&D in any program should not be understated. It is estimated that when R&D is completed, at the time of ATP (authority to proceed on production), only 4 or 5 percent of the program dollars have been spent. At this point, commitment of 75 percent of the production costs is made. The significance of this is obvious when one considers that private risk capital of over $5 billion was required to develop the U.S. wide-body civil transports. That's more than the net worth of the companies involved.

Obviously, it is errors in the 75 percent that cause managements' headaches, and a small change in the 4 percent for R&D can do much to minimize managements' risk. Clearly here is an area of great challenge for the aeronautical engineer because paradoxically, industry faces the problem to justify a way to pay for this R&D at the time it should be done.

Today, our total civil and military U.S. aeronautics R&D expenditures are increasing. As a nation, we are emphasizing these efforts with recognition that our future production programs come from such activities. We expect this trend to continue.

Unfortunately, one of the innocent sufferers of the economic crunch of the 1970 cutbacks is in the specific field of basic research and applied research applicable to civil aviation, see Figure 9. These two categories of R&D are not product related and are hard to justify to management planners, because they have minor impact on existing programs or possibly even on the next program. But they are necessary for the longer term. Unfortunately, this area in civil aviation in the U.S., which has long been funded by industry, has suffered the greatest, percentagewise. What used to be a billion-dollar national effort has been reduced to half that in 5 short years. Industry can no longer carry this burden alone as the struggle for profits is strong. This is an area where industry needs to work with universities to see that the government places proper focus on our national research needs. Without NASA and DOT and DOD assuming a greater effort in this area, we would expect the long-term objectives of U.S. civil aviation to be less than they might otherwise be.

CIVIL AVIATION EVOLUTION

Civil aviation history can best be described by looking at the dynamic sustained growth that has occurred in revenue passenger miles, see Figure 10. Obviously, the traveling public likes what it has been given. It has not been easy. Technology advancements were behind every step of improvement, see Figure 11. Improved productivity, by increased passenger capacity and speed, took massive investments in technology developments. The resulting benefits helped everyone: passengers, airlines, and manufacturers, see Figure 12. Dramatic improvements in safety practically eliminated passenger fears of flying. Fares effectively were reduced over 50 percent from the earliest days of air travel. Trip time from Los Angeles to New York, once 30 hours, is now 5, and flight above the weather has made travel enjoyable. These improvements made the U.S. an air-minded nation, both domestically and internationally. Relative to other consumer price rises, or alternate transportation price increases, air travel fares decreased steadily from 1947 to 1973, see Figure 13. Air travel remains one of the great bargains in our economy. The proliferation of special low-cost fares unfortunately has not brought the airlines glowing financial rewards. Today the U.S. airlines, our customers, are suffering a severe $2.5 billion short fall in earnings as compared to the 12-percent ROI (return on investment) set by CAB as reasonable, see Figure 14. This obviously has much to do with the recent slowdown in domestic sales of civil transports.

Inflation is eroding most technical improvements we seem able to offer, see Figure 15. From initiation of jet services in 1958, inflation has increased items of those turbojet aircraft direct operating costs faster than the increase in the consumer price index. Only fuel prices have resisted this trend, and the recent severe rises have now brought them above the CPI index as well. The DC-10 type advanced technology aircraft does offer decreased operating costs, but much of the technology gains were needed just to overcome inflation and environmental requirements. There is concern that the long era of technology advancements resulting in airlines with reduced operating costs may have run its course, see Figure 16. New designs are not yet losing ground and our industry still feels challenged to find ways to reduce costs.

FORECASTS - OPPORTUNITIES

Real growth in GNP dropped in 1970 and in 1974, see Figure 17. McDonnell Douglas expects it to be positive again in 1975 and through 1980 and on, with the total GNP growth rate remaining around 8 percent. GNP is a dominant variable in much of our market forecasting.

We continue to track the progress of the European countries and Japan in aerospace activities. Their employment tends to be stable or growing as compared to ours, see Figure 18. The same is true for sales, see Figure 19. Their significant gains in productivity, output per man-hour, see Figure 20, are doing much to offset inflation, and there is little question but what the efforts of these countries to secure a significant share of the high technology aerospace sales markets will affect our U.S. industry. It will impact on both civil and military sales as these nations strive to obtain exports to offset the huge oil import demands.

At present, as U.S. unit labor costs have been held relatively stable, the devaluations of the dollar have provided U.S. manufacturers with a decided advantage over other nations, see Figure 21. How long the U.S. can enjoy this advantage remains to be seen.

We forecast a 45-percent growth, by 1984, in annual U.S. defense funding with a slightly reduced level of growth for industry because of increasing in-house DOD costs, see Figure 22. From this, aerospace defense annual sales should increase to $19 billion from the present $13 billion, a 45-percent increase, see Figure 23. Taking inflation into account, this still represents an increase in effort required, showing that the decline has in fact reversed. In the military aircraft market, we expect annual sales 70 percent greater than today, see Figure 24. This is a significant increase, even when corrected for inflation, and to accomplish it will require concerted technology efforts by an increasing engineering work force.

For NASA we envision funding at or near $3 to $4 billion annually although 92 percent is for space - only 8 percent for aeronautics, see Figure 25. We seriously feel that NASA should face up to a major expansion of their aeronautics budget. This important R&D effort has not kept pace with the old NACA budget when corrected for inflation. This represents a sadly neglected area in our national heritage and one in which the average citizen of our country took great pride. It should not be so neglected.

In the commercial field, see Figure 26, the world requirement for new aircraft by 1983 will equal today's value of all airline aircraft. By 1988 this requirement will double. This translates into $115 billion. It means $6 billion in annual sales in 1983 and over $12 billion in 1988.

It remains to be seen how well the U.S. will be able to retain its present ratio of having produced 93 percent, by value, of the free world's civil transports. The stakes are huge and the pressures are mounting to make our task more difficult. We have no shortage of problems to address.

The kinds of new airplanes required, see Figure 27, fortunately include large numbers of wide-bodied aircraft where the U.S. position is already well established. We are also well along on our YC-15 short-field transport development prototypes, the first of which is scheduled to fly in 1976. We have high hopes for future successes here, both military and civil. Our cargo efforts are equally as dynamic and recently we announced an all-cargo version of the DC-10. In civil supersonics, McDonnell Douglas is probably spending more of its own dollars than our competitors adapting the knowledge we have gained in over a decade of supersonic fighter and research aircraft experience. Coupling this with the NASA technology base, Boeing experience on the last SST, and the SR-71 experience at Lockheed gives the U.S. a strong technical base for a second-generation SST.

In total, we see significant growth ahead for our aerospace industry, especially in aircraft, see Figure 28. The commercial transport markets are increasing, NASA is expected to expand slightly to hold a level work force, the military missiles and space should do likewise, and the military airplane business should grow.

We might heed Dr. Von Karman's comments as we consider aeronautics for the sake of society. He said scientists tend to study what is, while the engineer creates what has never been.

More challenging, exciting business opportunities for creative individuals would be hard to define. Major aeronautical problems are crying for solutions that only engineers can provide. We must get this message out to the youth of our country.

RESPONSIBILITIES

Each of us has a share in our tasks ahead, see Figure 29. As we study the data available on new graduate engineers and see the estimates for supply and demand diverging, it becomes obvious that we, jointly, have a great deal of work to do. We are forecasting even more divergent paths on the supply of new aeronautical engineers, as shown earlier. The class of 1974 saw 43 percent of the job offers tendered to engineers, who were only 5 percent of the total number of graduates. The supply of engineers did not meet the demand.

Pay scales obviously play an important part in the supply of engineers. Russia is a good example as there the engineers enjoy the highest rewards, ahead of physicians and lawyers. Her schools now graduate five engineers for every one we graduate. The incentives are strong to attract the finest students. Their latest plan calls for having trained one and one-third million engineers by the end of 1975, one-third more than our engineering work force. They have come a long way in a short time.

In the U.S., aerospace engineers enjoy a higher average salary than the average of all manufacturing industry engineers, see Figure 30. Comparing engineers with other occupations, it should be noted that the number of aerospace engineers in the highest ranks of management is large, as most aerospace companies are headed by aeronautical engineers. Also, increased company emphasis on fringe benefits and earlier retirements are doing much to improve the rewards of aerospace engineers relative to other professions. Based upon 1970 census data, the medical and legal professions, on the average, are the best paid of 423 occupations identified. They are followed by optometrists, airline pilots, veterinarians, actuaries, physicists and then aeronautical engineers, in 12th place. And the data show the aeronautical engineers were employed a greater percent of the full year than for any of the first 11 occupations.

Special note should be made that the median earnings of women aeronautical engineers rank fourth out of 391 occupations depicted in the 1970 census, behind women lawyers, judges and physicians. Perhaps we should direct more attention to encouraging women to become aeronautical engineers. Our company has a number and they are doing an outstanding job. We encourage you in education and government to publicize aeronautical engineering careers for women and hopefully we will see more of them enroll in engineering schools.

At McDonnell Douglas we are addressing the question of how best to increase the rewards to an engineer for doing a professional design job. We are studying financial rewards based upon education, experience and, most importantly, individual contributions. We want to provide a total benefit package which is designed with the professional's interests in mind.

We don't have all of the answers yet, but we intend to see to it that he feels satisfied with his total work environment. We must provide innovative incentives to keep this talent from drifting into other areas or to other duties inconsistent with his training.

We are trying to assume our responsibilities as employers. We feel it important that you as educators recognize your responsibilities as well. Because roughly 70 percent of "your" engineering students will go to work for someone in industry, industry interests must continue to be recognized, see Figure 31. It would seem valuable for educators to remember how the engineer sees himself. Recent surveys show that two-thirds or more of engineers at age 40 are in supervisory positions. Twenty percent of engineers report their prime function as planning or directing efforts, followed by design (18 percent), advising (11 percent), development (9 percent), research (8 percent), production (7 precent), sales (6 percent), teaching (5 percent) and miscellaneous.

To be successful, two items seem paramount as a result of studying the survey of an engineer as he sees himself. First, is the need for engineering excellence. Second, is the high degree of management responsibilities demanded, something normally neglected in the formal education of an engineer.

We see an increasing need to broaden the education of the engineer. In addition to technical specialization, we place increased emphasis on engineers to handle formal business responsibilities. He must address the social, economic and political aspects of aerospace. We fully recognize that engineers follow dual roles as they mature in industry, advancing up a technical ladder or a parallel managerial ladder. Both are important and both are ways of life in industry.

Engineers must be taught to speak effectively, write effectively, communicate well, and, hopefully, do some of these in two languages. International cooperation has become an integral part of our aerospace activities.

Research-oriented universities providing graduates for product-oriented industry require careful coordination or the graduate is not trained as well as he might be.

Because colleges emphasize theory, industry must teach the design or synthesis process. An apprenticeship to an outstanding design engineer is a practice forgotten in today's pressure of solving problems. The old-time design engineers, whose names adorn our companies, the Martins, Douglases, McDonnells, are becoming a thing of the past. We are conscious of this void as more of our engineers specialize as analysts in lieu of seeking design engineering jobs. The medical profession is not alone with problems of overspecialization.

Improved quality instructional materials as used in industry need to be brought into the engineering students' curriculum, see Figure 32. The much publicized Stanford, University of Washington and MIT design engineering courses are good examples where industry cooperation is working. Our industry needs to support more of this and I encourage NASA to assume a leadership role here and develop similar programs throughout our country. Motivated students would result, and further job satisfaction as well, for each NASA or industry aeronautical engineer as he participates in such a program.

The National Science Foundation sponsored summer workshops and the similar NASA program in the late 1960's offered good interchange. I would encourage NASA to set up aeronautical workshop projects and make them a permanent part of our national aeronautics R&D program. We offer our cooperation.

Recent trends in education emphasizing science and research need rebalancing. With our space program this emphasis was fine because the problems were so new. Now, creative design engineering must be brought back into perspective as we focus on society's needs. Students need to be prepared to deal with total value analyses of real life complexities, including simplicity and cost, which are so typical of good design engineering.

Our nation needs to learn to reward our engineers and scientists better to stop the trend away from technology. The technology leadership in the world will obviously go where there is no shortage of fine talent working to solve the complex problems of society.

As for technology, see Figure 33, we see future emphasis for aeronautics directed toward realizing the synergistic benefits that come from coupling technologies. Doing a perfect propulsion design job on a nacelle and an ideal aerodynamic design on a wing is no longer satisfactory. Tomorrow, the inter-discipline coupling for performance improvement will be so great that revamping of traditional design responsibilities probably will be necessary. Additionally, we see emphasis on basic aerodynamics, structural materials and design, and burgeoning usage of computers for design, control and general communications. Call it cybernetics if you wish, the science of control and communication in humans and machines. Hopefully, we will progress to the point that airplane design becomes truly a science more than an art. You educators have a big job to prepare an engineer for the tasks ahead.

That the challenge to an aerodynamicist still exists may be seen in the half humorous, half truthful definition used by A.M.O. Smith of Douglas in this year's Wright Brothers Lecture to the AIAA, "....an airplane is a device that almost won't work."

Civil aviation began because of the dedicated pursuits of individuals to overcome problems of air travel. Now the responsibilities are different. The military will no longer provide the developed technologies it once did. Civil transports now must be planned to provide the correct balance for society as a whole: economics, noise, service, safety, relationships to total transportation systems, balance of trade, jobs, leadership, finances, politics, etc. The list of values that must be included by the engineer in his planning is large. His actions can have a major impact on how we live in the world of tomorrow. Our ability to select how we want to work, when, and with what total environment or lifestyle are prime goals of this generation of today. An efficient air transportation system fits directly into this picture and changes across the face of our nation can happen. The unpleasing styles of life in many of our nation's cities can probably be changed if we challenge and improve transportation. Aeronautical engineers can effect such changes. We need a flow of bright challenged graduates and all of us should help to see that the supply is continuous.

May I leave you with this thought? One person, speaking to one youngster, is the way a career in aeronautical engineering gets started. Massive publicity campaigns won't do.

When was the last time we sat down and talked aeronautics to a freshman engineer? When did we last send one of our best aeronautical professionals to address a science class? Think about it. We need aeronautical engineers and the way to obtain them is direct contact, one on one.

SUMMARY

In order to make all the things happen as I've described them here, certain crucial constraints must be overcome, see Figure 34. Federal realization of the importance and responsibilities of proper government action is mandatory.

Airline profitability must be accomplished and past mistakes corrected. We the manufacturers must return to profitability commensurate with our risks and efforts. Profits, not prophets, foretell the future. And our federally supported programs for basic research, applied research, exploratory development, and development need be continued aggressively in both military and civil aeronautics.

As government and industry leaders, we must address the questions of motivating new students into engineering, doing what is necessary to challenge their creativity and keep them employed as engineers, or we can expect long-term threats to our leadership position in aerospace.

Obviously, we are not communicating our needs to certain students for them to make the most of their lives. Opportunities exist and these need to be identified and publicized. In the airplane field, I think the future is full of promise, see Figure 35. The challenges are exciting, and rewarding careers await those who choose to follow a professional life in aeronautical engineering.

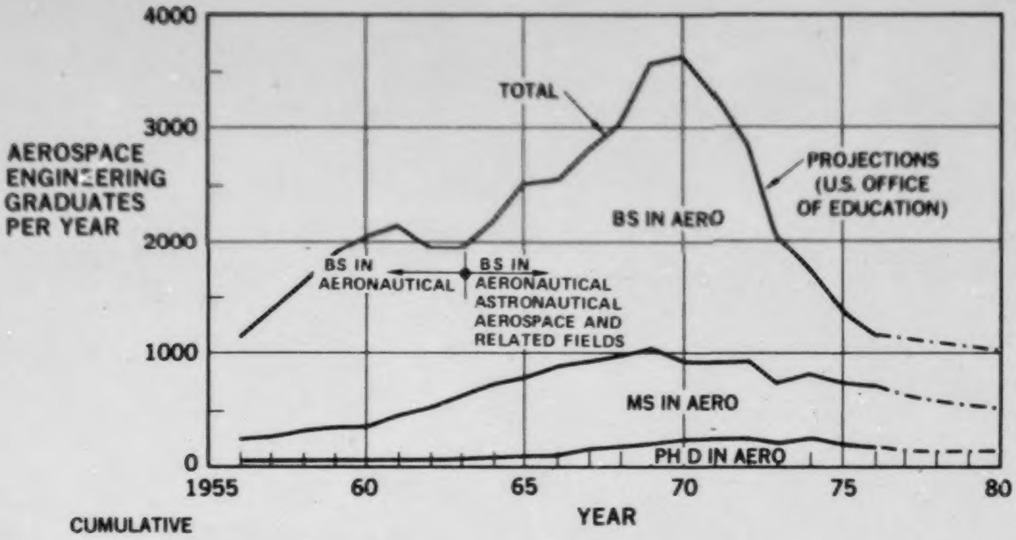

Figure 1.- Aerospace engineering graduates.

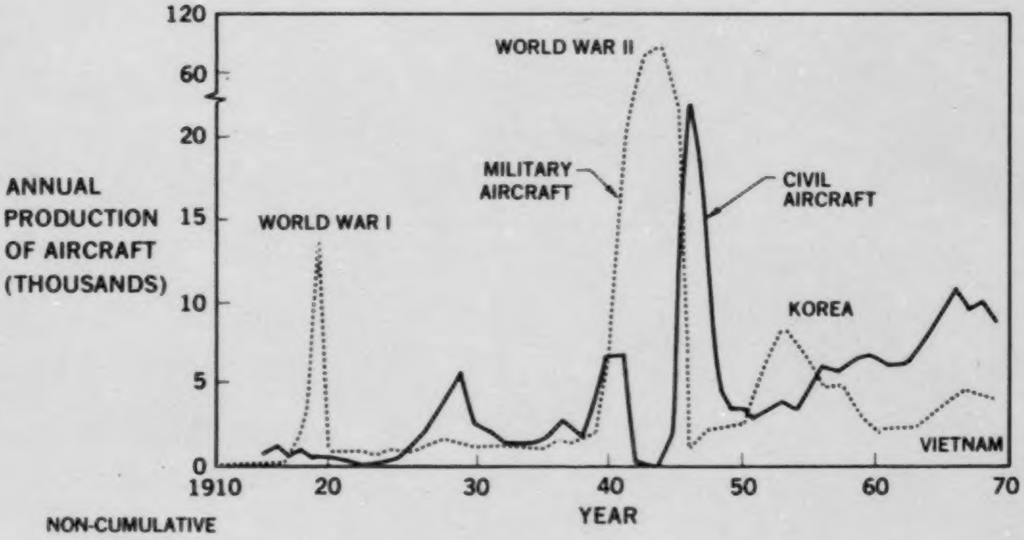

Figure 2.- U.S. aircraft production - all types.

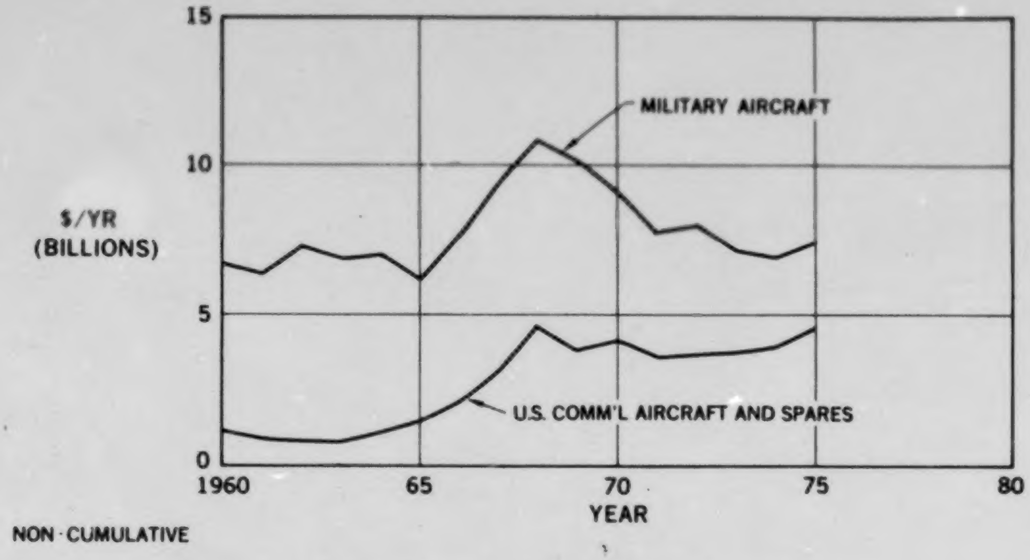

Figure 3.- U.S. aircraft sales (current dollars).

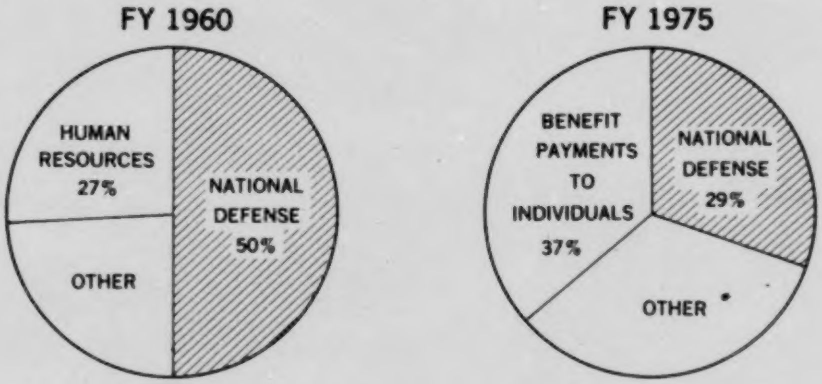

Figure 4.- Changing composition of the federal budget.

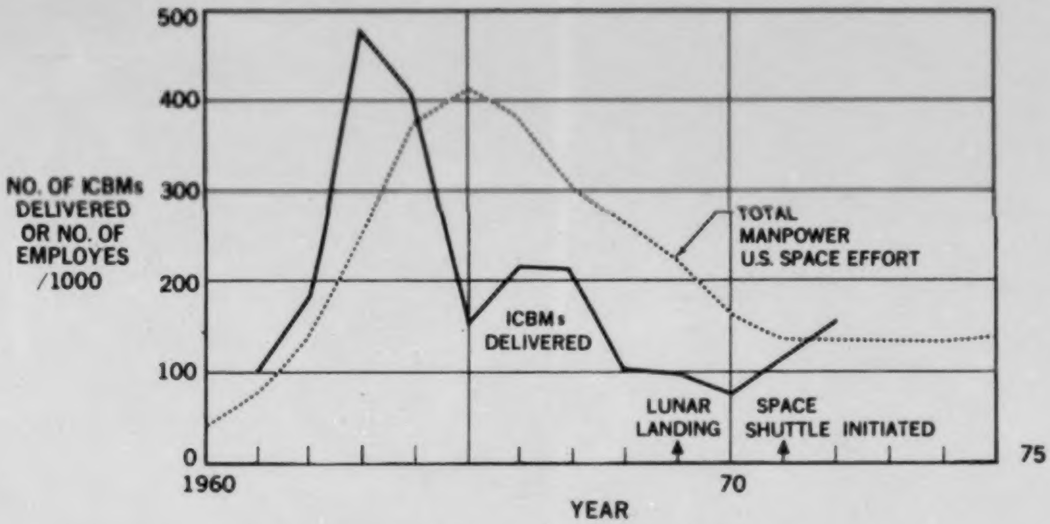

Figure 5.- Space/missiles ascension.

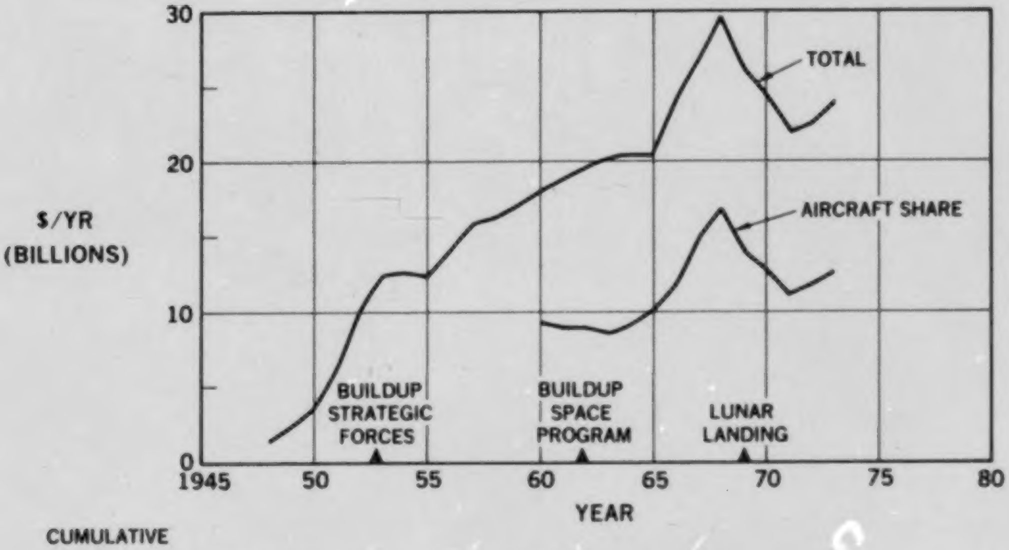

Figure 6.- Aerospace industry total sales.

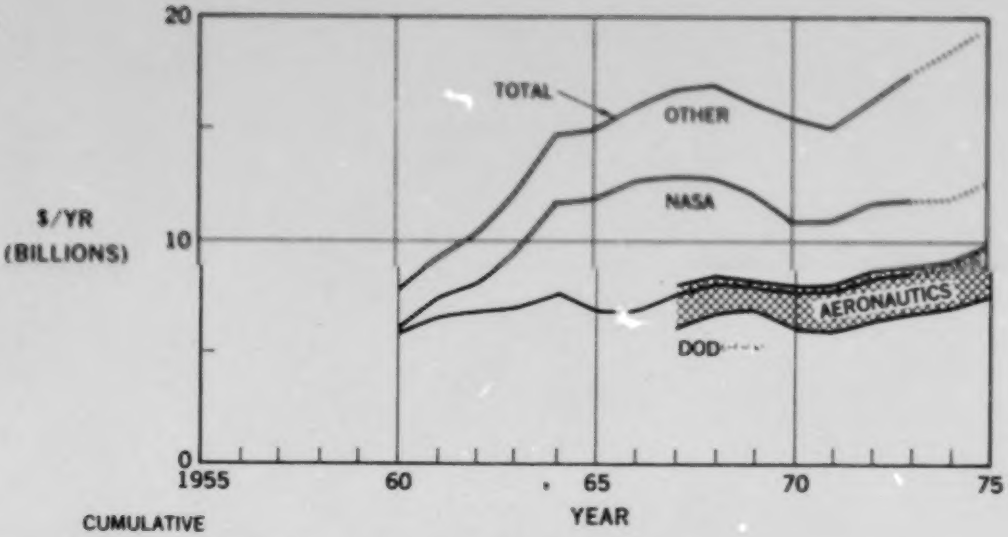

Figure 7.- Federal outlays for R&D.

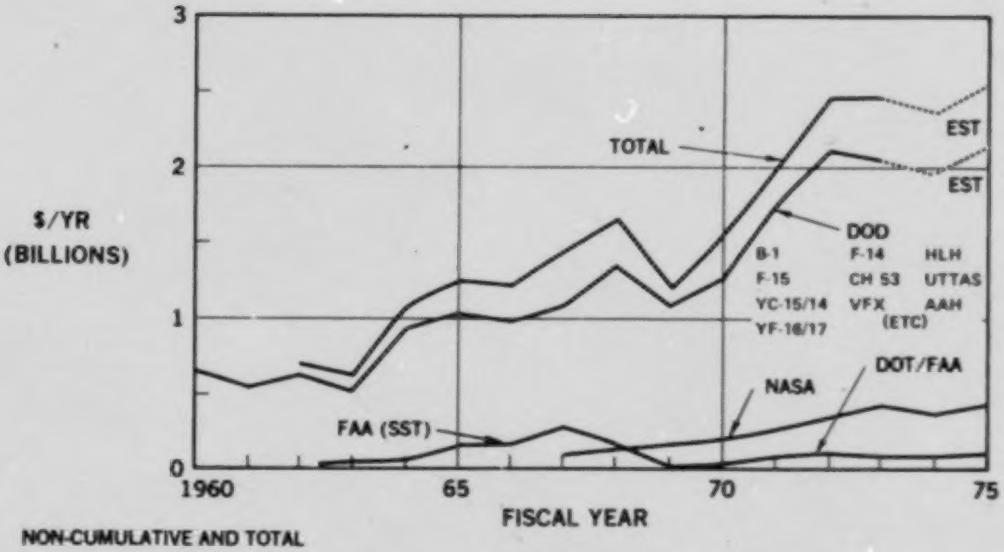

Figure 8.- Federal aeronautics R&D (new obligational authority).

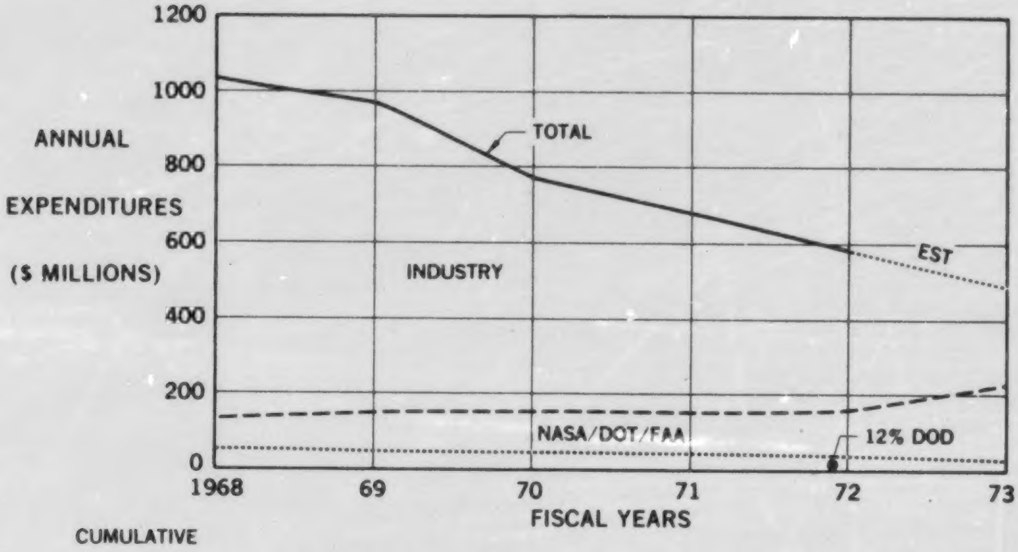

Figure 9.- Basic and applied research applicable to civil aviation (1972 dollars).

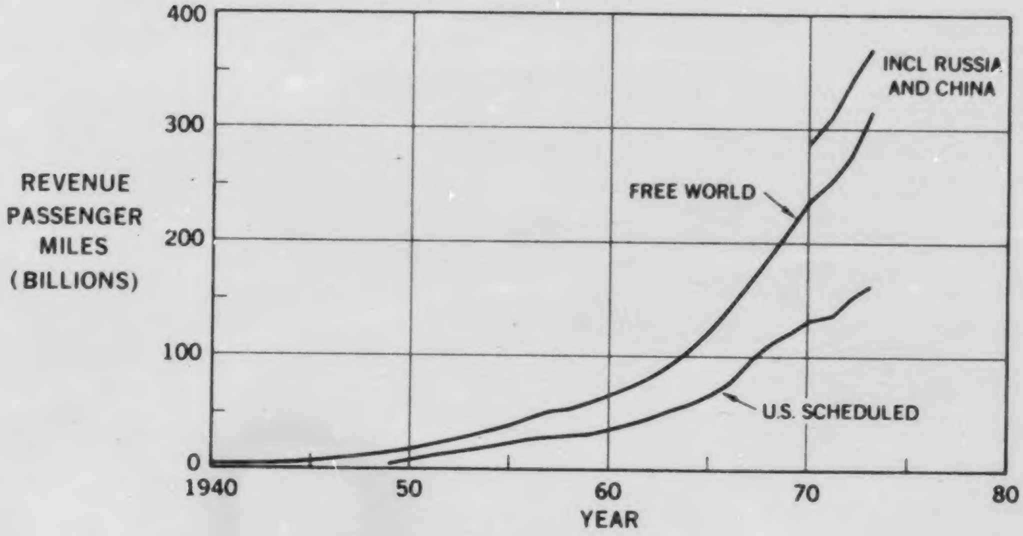

Figure 10.- Airline traffic - scheduled airlines (ICOA only).

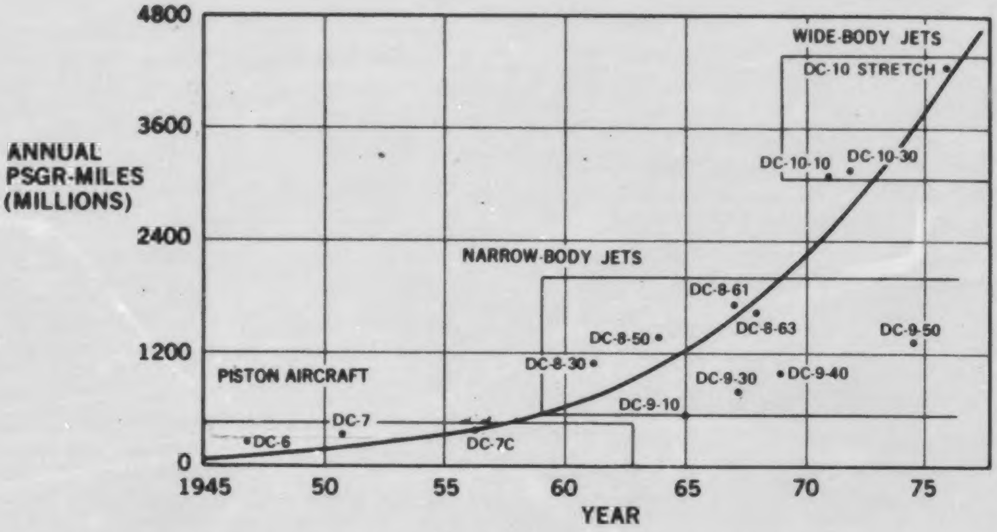

Figure 11.- Aircraft productivity versus time.

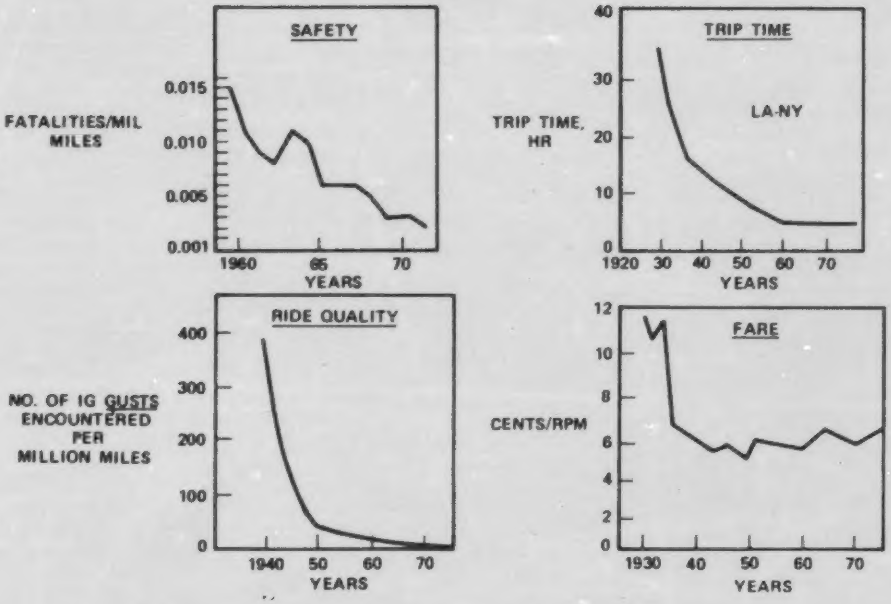

Figure 12.- U.S. airline passenger benefits.

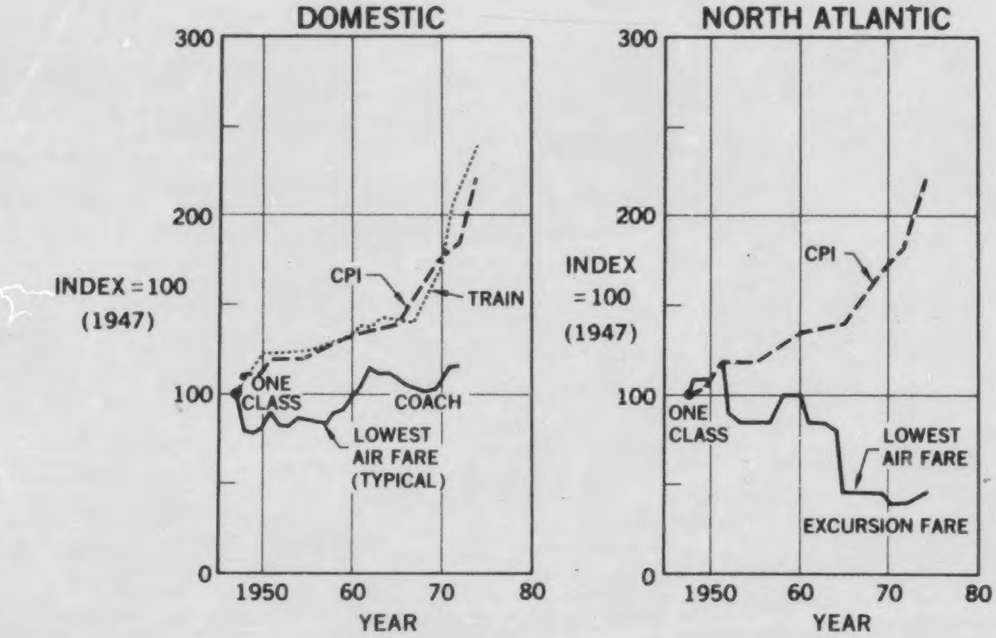

Figure 13.- Transportation fare trends versus consumer prices.

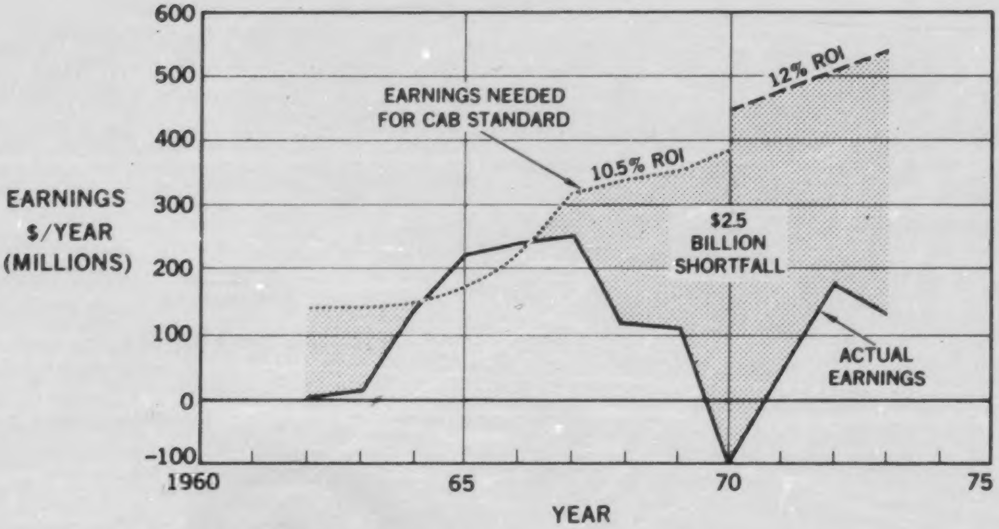

Figure 14.- Domestic airline earnings short fall (against CAB standard).

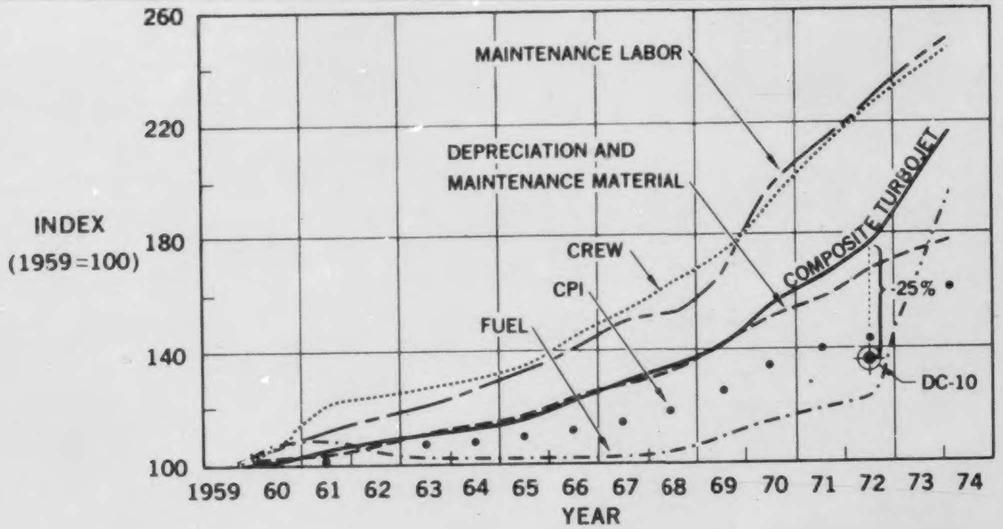

Figure 15.- Direct operating cost inflation of turbojet aircraft (U.S. airline operations).

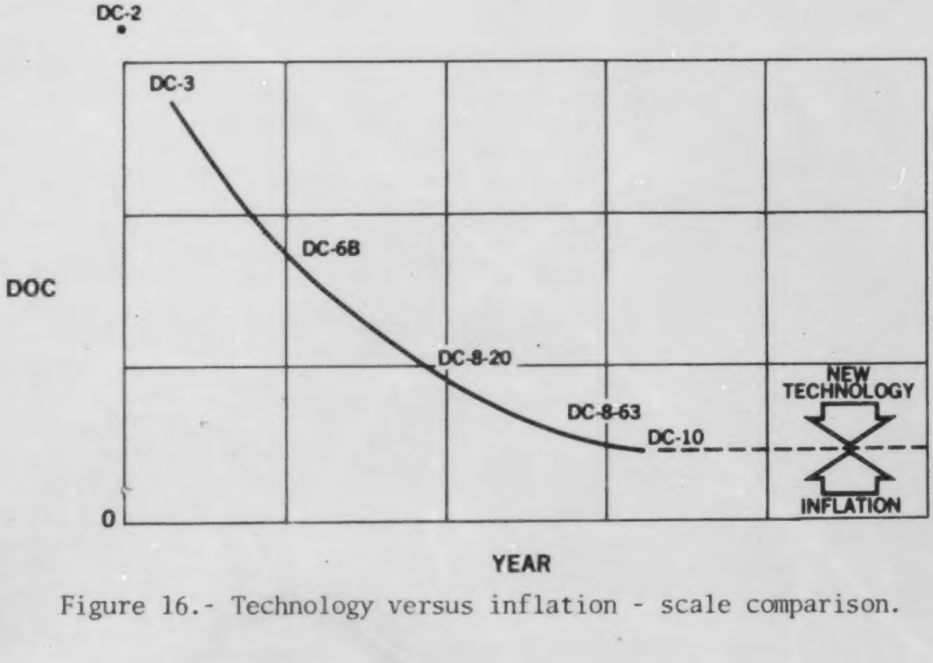

Figure 16.- Technology versus inflation - scale comparison.

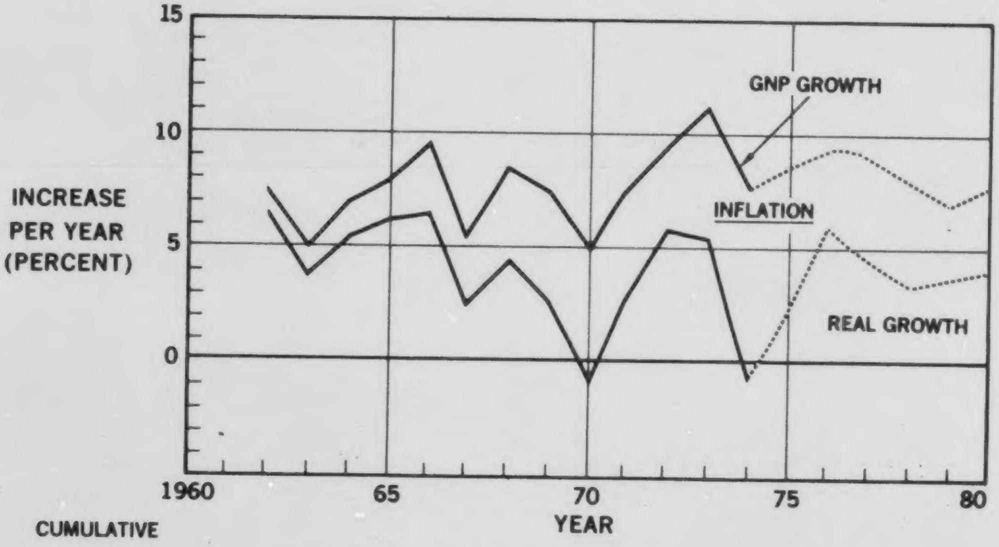

Figure 17.- Long-term U.S. economic growth and inflation.

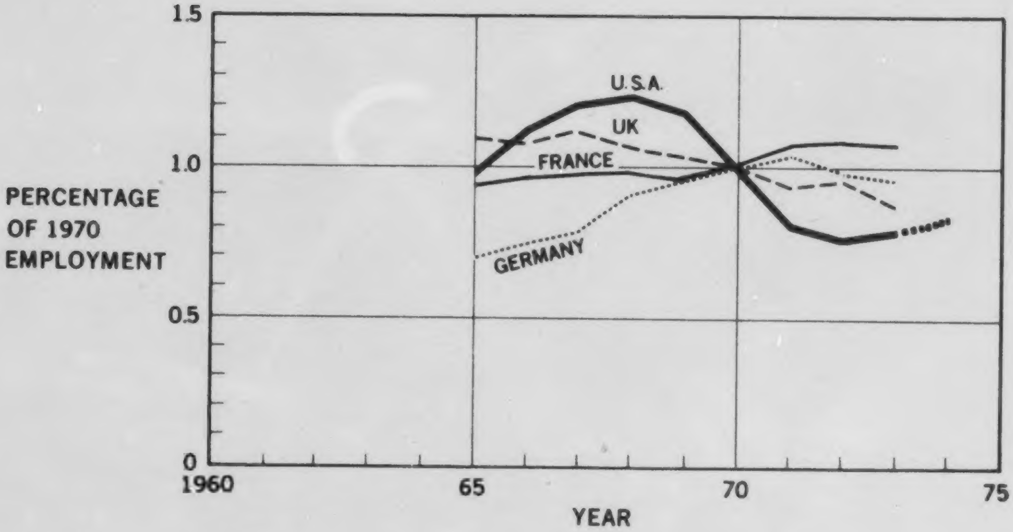

Figure 18.- Aerospace employment (ref. 1970).

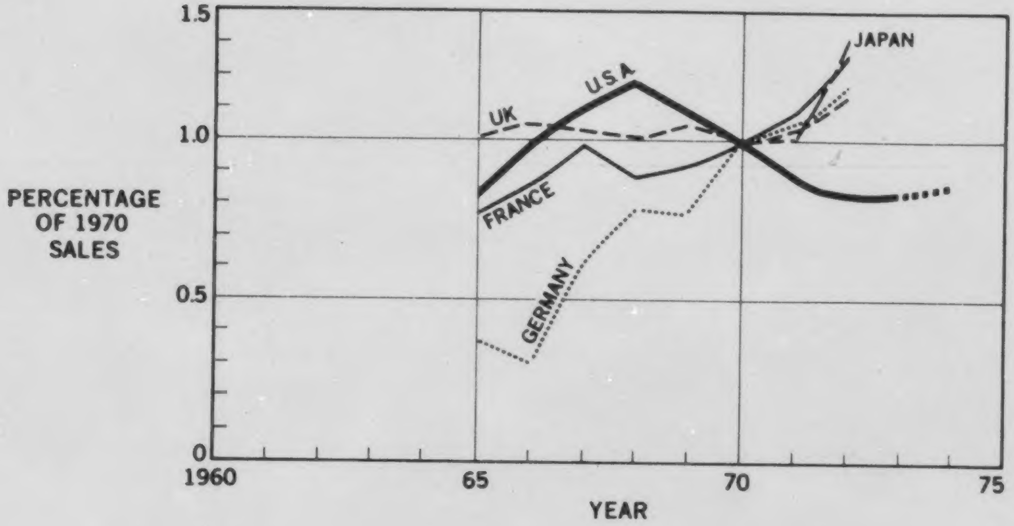

Figure 19.- Aerospace sales (ref. 1970).

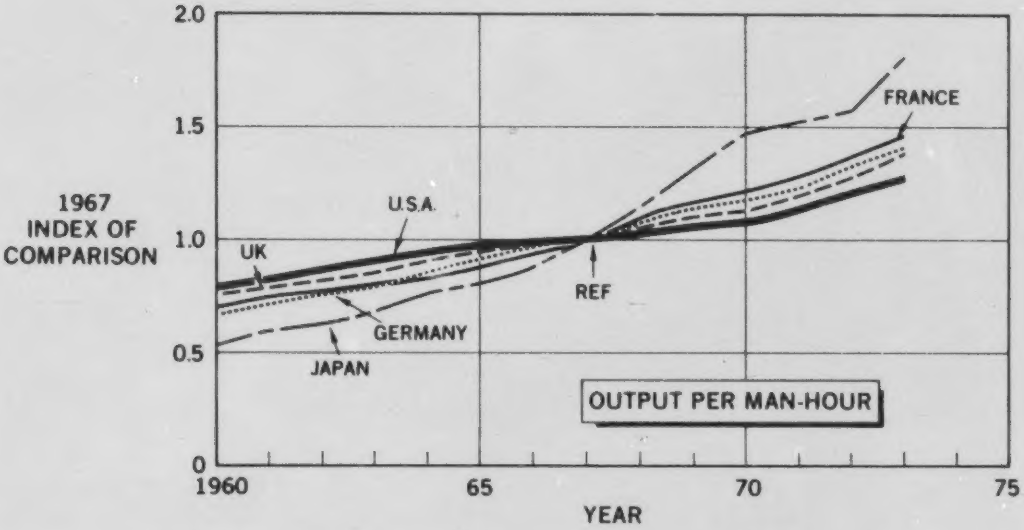

Figure 20.- Comparative productivity (manufacturing).

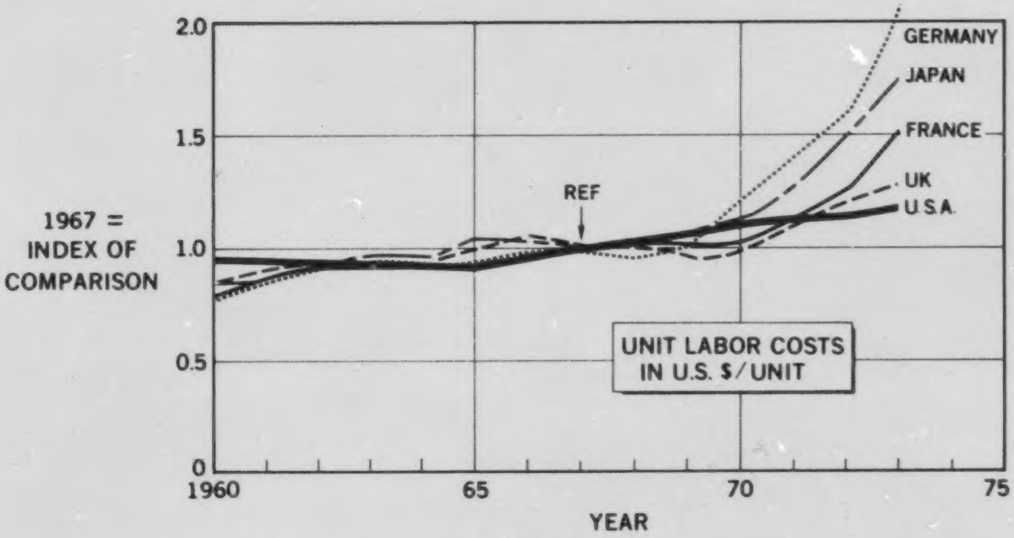

Figure 21.- Comparative unit costs (manufacturing).

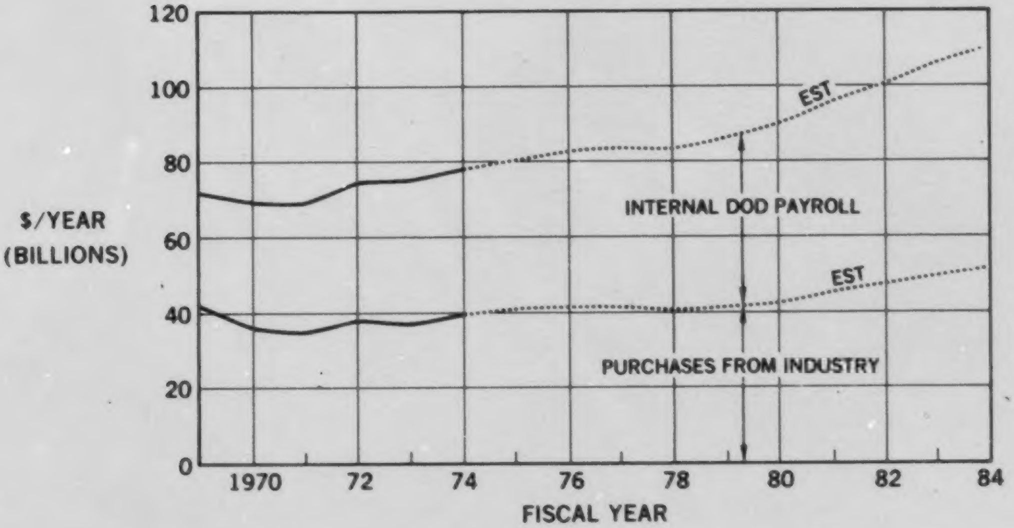

Figure 22.- U.S. total defense funds (current prices).

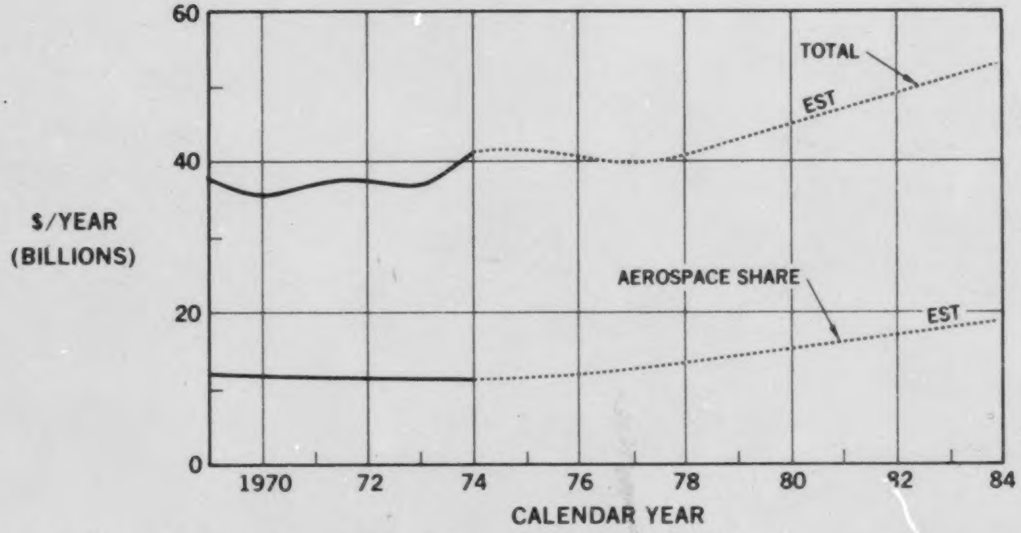

Figure 23.- Total defense market - purchases from industry, prime contract awards (current dollars).

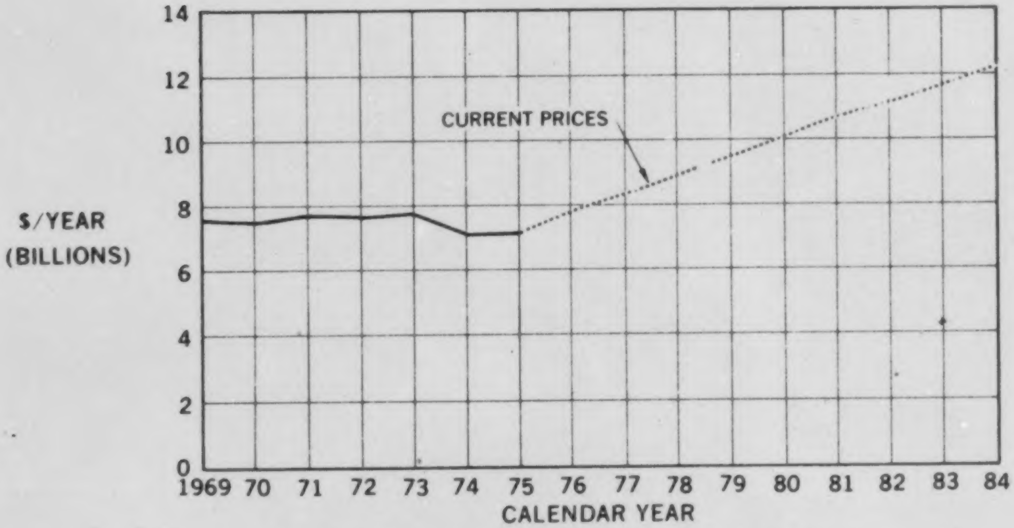

Figure 24.- U.S. military aircraft market - purchase from industry, prime contract awards.

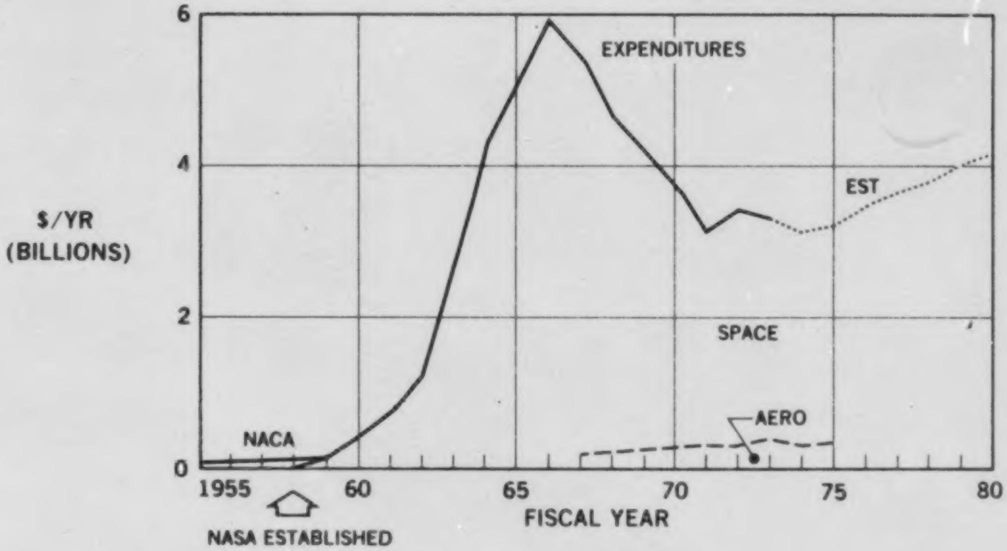

Figure 25.- NASA aerospace expenditures.

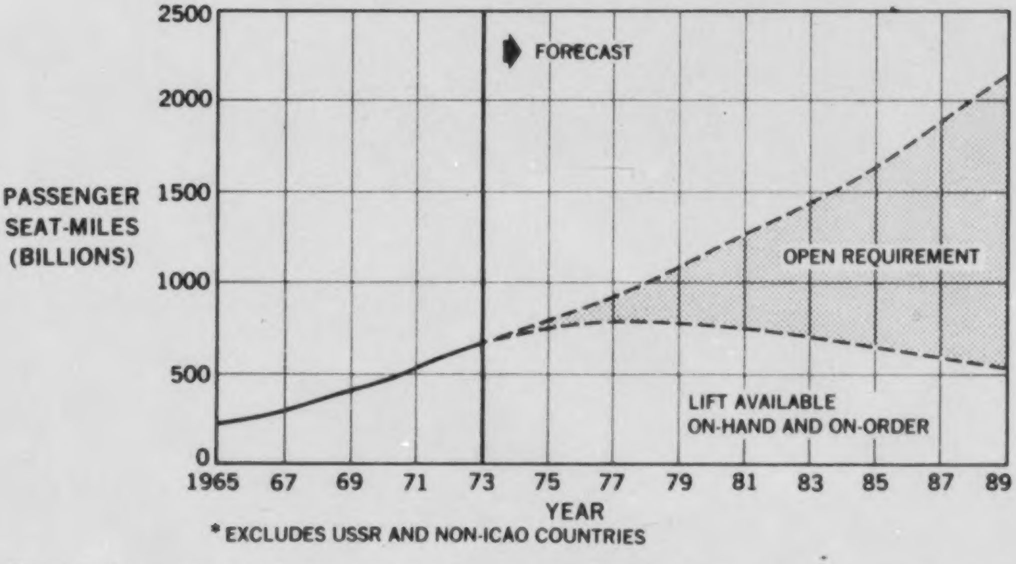

Figure 26.- World open airlift requirements (all passenger services).

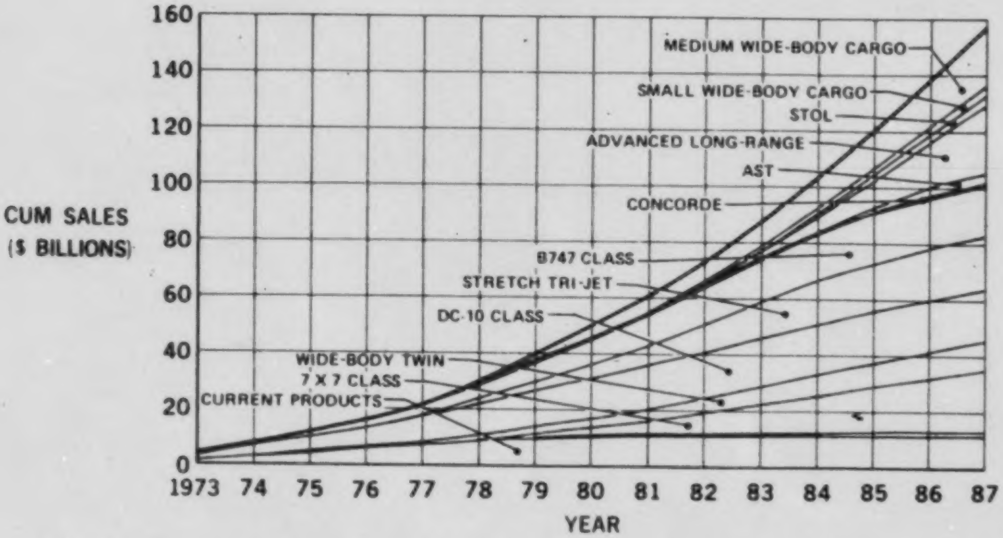

Figure 27.- Future commercial transport market (current dollars).

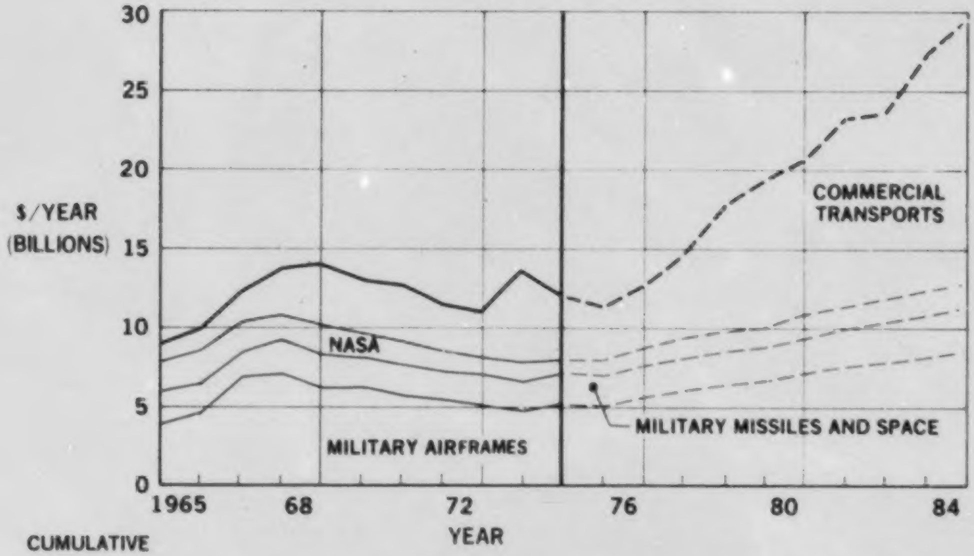

Figure 28.- Total MDC aerospace markets (current dollars).

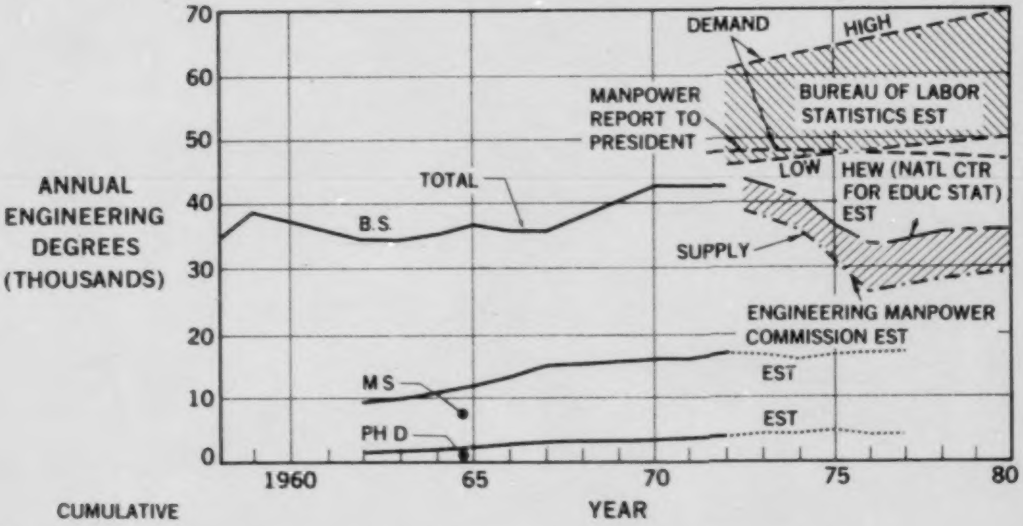

Figure 29.- Graduating engineers - supply and demand.

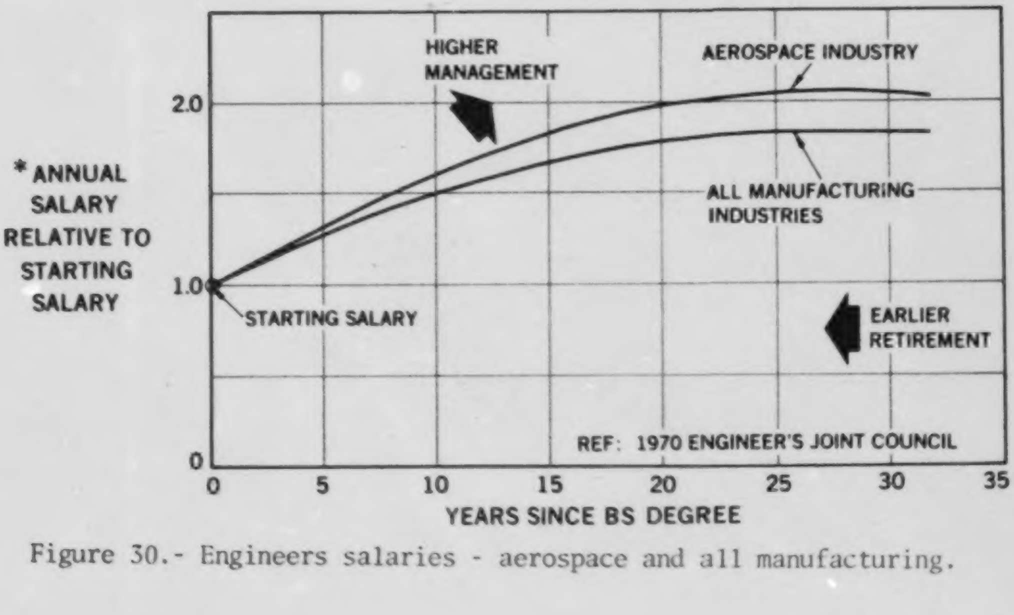

Figure 30.- Engineers salaries - aerospace and all manufacturing.

EMPLOYER	
PRIVATE INDUSTRY	69%
FED GOVT — CIVIL EMPLOYE	8%
COLLEGE	7%
SELF	4%
DUTIES	
PLANNING, DIRECTING	20%
DESIGN	18%
CONSULTING	11%
DEVELOPMENT	9%
RESEARCH	8%
PRODUCTION	7%
SALES	6%
TEACHING	5%

Figure 31.- Profile of an engineer.

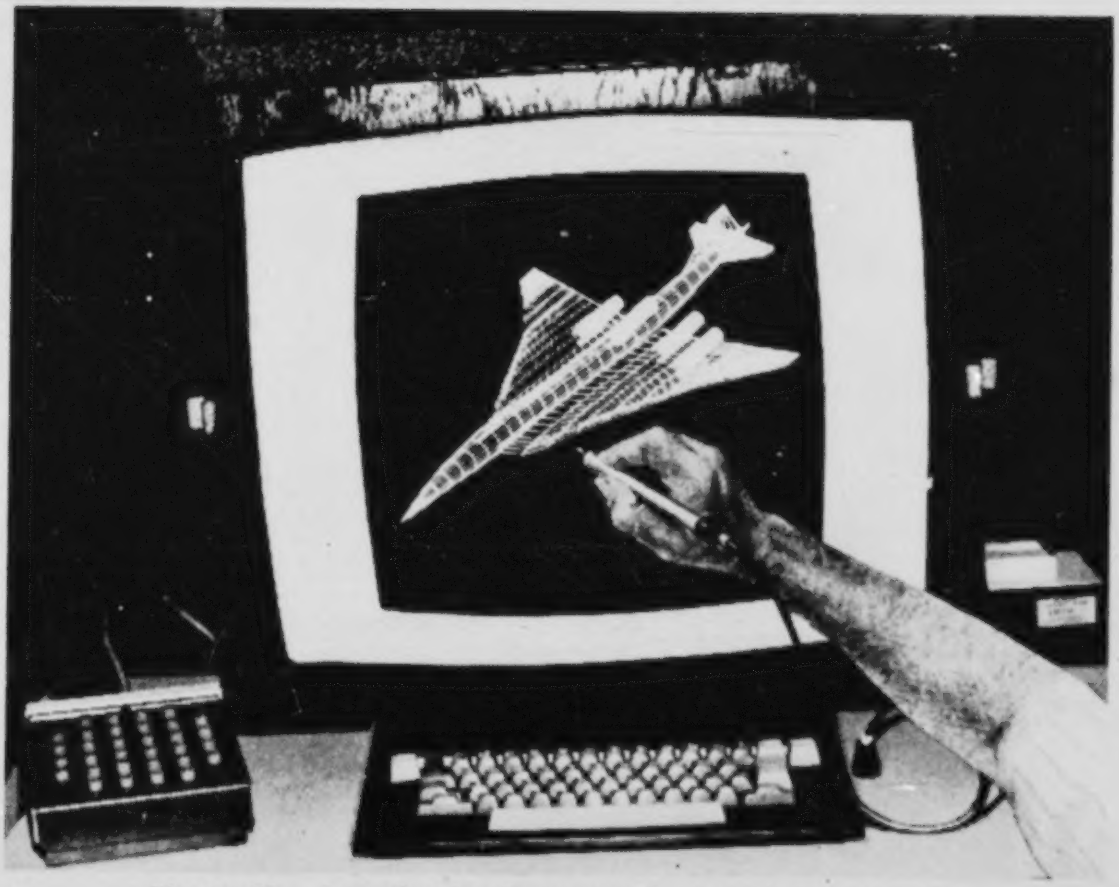

Figure 32.- A professional aeronautical engineer at work.

- INTERDISCIPLINE COUPLING
- AERODYNAMIC EFFICIENCY
  - LOW AND HIGH SPEED
- STRUCTURAL EFFICIENCY
  - MATERIALS AND DESIGN
- COMPUTER APPLICATIONS
  - CONTROLS, OPERATIONS, SYSTEMS
  - DESIGN
  - MANUFACTURING

Figure 33.- Future technology emphasis.

- AIRLINE PROFITABILITY
- MANUFACTURERS' PROFITABILITY
- FOREIGN MULTI-NATIONAL PROGRAMS
- CIVIL AIRCRAFT/ENGINE R&D

Figure 34.- Significant constraints.

- DEMAND IS INCREASING
- CHALLENGING JOBS ARE AHEAD
- RECOMMEND —
  - REWARDS BE INCREASED
  - TOTAL WORK PACKAGE IMPROVED AND STABILIZED
  - ONE-ON-ONE RECRUITING
  - FACULTY DESIGN WORKSHOPS FORMALIZED
  - DESIGN SEMINARS FORMALIZED – USING INDUSTRY AND GOVERNMENT
  - EMPHASIS IN EDUCATION ADDED ON:
    - CREATIVE DESIGN ENGINEERING
    - COMMUNICATION
    - MANAGEMENT AND BUSINESS
    - FOREIGN LANGUAGE
  - OPPORTUNITIES AND DEVELOPMENTS PUBLICIZED
    - PUBLIC AND MEDIA
    - ENGINEERS
    - WOMEN

Figure 35.- Summary - aeronautical engineers.

THE PREDICAMENT OF AERONAUTICAL ENGINEERING EDUCATION AND WHAT WE CAN DO ABOUT IT

By Arthur E. Bryson, Jr.
Stanford University

THE PREDICAMENT

The past few years have seen massive layoffs in the aerospace industry, cancellation of supersonic transport development, a reduced space program, a reduced military airplane program, reductions of federal research support in universities, cancellation of NASA and NSF traineeships, and reduced financial support from industry. Students interested in aerospace are understandably avoiding the aerospace label for something else entirely or for something more general and flexible. The resulting enrollment decreases have caused some Aerospace Departments to merge with Departments of Mechanical Engineering, Applied Mechanics, or Engineering Science, while many others are considering merger and/or diversification. Some Deans of Engineering are asking if aerospace engineering has perhaps reached the stage that railroad engineering reached in the 1930's. The low status of engineers in our society has been re-confirmed and even worse, we have been accused of causing most of the world's problems. Industry has been careless in its personnel policies toward engineers, and many engineers are now rather cynical about engineering as a "profession." The universities have tried to be too many things to too many people, and faculty have been arrogant in their judgments about industry and government. The U.S. has hit a new low in world-wide popularity. At home we are experiencing a crisis of trust in our leadership and in each other. Our expectations as well as our dollars have been inflated.

SOME CHALLENGES

On the other hand the aerospace industry is still one of the largest in the U.S. (approximately $20 billion a year, down from $30B in 1968). Air travel has completely supplanted rail and ship travel for long distances and the long-term trend in such travel seems steadily upward. Space travel and research have changed the perspective we have of ourselves in the solar system almost as much as Copernicus changed our perspective a few centuries back. We are challenged to build aircraft and spacecraft that are cheaper, more efficient, quieter, faster, capable of short take-offs and landings, and less of a disturbance to the environment. We are challenged to extend our purview beyond the vehicles themselves to improve air traffic control, airport operation, surface transportation, ocean engineering, bio-medical engineering, and energy conversion.

In many respects our uncertainty is caused not by a lack of challenges but by too many challenges -- which ones should we concentrate on? This is not so bad a predicament to be in!

RANGE OF AEROSPACE ENGINEERING CAREERS

There is a tremendous diversity in aerospace engineering career opportunities: scientific research, technology development, engineering design, maintenance engineering, and operational planning, to name but a few. Our educational system is, and should continue to be, correspondingly diverse. Some schools should continue to emphasize the basic science of aeronautics, while others emphasize technology development, etc. However, all of us should try a litte harder to understand and appreciate the roles that others play in the field. We should remember that professors are seldom inventors, technical managers, or entrepreneurs, and that we need good people in such positions if the industry is to remain viable.

EXPERIMENTAL RESEARCH & DESIGN MOTIVATION

In the last 15 years many of our engineering schools have neglected experimental research, laboratory experience, and motivation for design. We have hired young Ph.D's right out of school and most of them have had strong inclinations toward analysis and basic science. As a result our communications with industry and experimental research centers like NASA have become inadequate to say the least. Our aerodynamicists have deserted the AIAA for the American Physical Society, while the AIAA journals have become full of straw-man analysis problems. Many professors disdain design problems, and some, I'm afraid, don't even know what design is. Most of us are out of date with respect to the design aspects of our special fields.

However, in fairness, the fault is not all ours. The aerospace industry does a lot of classified work and it has many trade secrets. If you have ever tried to liven up some of your problems with realistic numbers, you know how difficult it is to find data on current aircraft, and that it is almost impossible to find data on current engines.

We need to hire some faculty members who have been successful designers. We should encourage leaves of absence for professors, particularly young ones, to work in industry. We should provide more student laboratory experience with up-to-date equipment and interesting subjects.

REORGANIZATION

I think we might question whether departments of Aerospace Engineering are still appropriate in some engineering schools. The industry has diminished in size and it has diversified and become essentially a high-technology industry. Education in basic subjects like solid and fluid mechanics, electronics, thermodynamics and heat transfer, structures, information processing and computers, with a design motivation and an acquaintance with some current instrumentation and devices, prepares a student to enter many fields of engineering and to maintain a flexibility that is almost essential as new technology continues to develop.

I am also concerned about degrees beyond the M.S. in engineering. The Ph.D. should not be the only respected degree; it is a research degree and is often inappropriate for students who wish to do technology development in industry or NASA. I suggest that we try to elevate the degree of Engineer (and possibly also Applied Scientist) to greater respectability; perhaps this could be done by making it the next goal after the M.S., obtainable normally by one more year of study and a small thesis which could be a project, possibly design oriented, and need not be original research.

WHO SHOULD BE ENCOURAGED

I believe that an intelligent young person who obtains at least an M.S. degree in aerospace engineering, who is enthusiastic and conscientious in his work and who continues to learn, will be able to find fascinating and rewarding careers in air transportation, space applications and exploration, military applications, or associated new technology developments.

THE HUMAN DIMENSION

Men and women are more than engineers or scientists. They take pleasure in art, music, drama, sports, and travel. They enjoy the beauties of nature, ties of friendship, and the love of their families. Industry and government must do better than they have in encouraging employees to develop their talents, in treating them honestly and fairly with respect to promotions and pension plans, and in informing them about what is going on within the organization. Even though our curricula are necessarily built on science, we should encourage, not just tolerate, the study of history and the humanities which help to provide meaning for our lives. Technical competence and the ability to think are essential but a sense of values, a sense of direction, and above all a spirit of commitment and enthusiasm make all the difference between a dreary nine-to-five job and an exciting, rewarding career.

THE PREDICAMENT OF AERONAUTICAL ENGINEERING EDUCATION AND WHAT WE CAN DO ABOUT IT

By R. J. H. Bollard
The University of Washington

THE SCENE

The enrollment drop over the last five years at the University of Washington in the department of Aeronautics and Astronautics has been dramatic and this experience has been painfully shared by most similar departments in this country. The enrollment figures for the Junior (3rd year) class are as follows:

1969	85	1972	22
1970	65	1973	17
1971	35	1974	22

The department retains a graduate enrollment of 75 and has a faculty of 18.

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During this same time period there have occurred the winding down of the Vietnam war, the conclusion of the Apollo program and the awakening interest in our society in environmental and social problems. The effect of these factors on A&A departments has been, or will be, developed in detail at this conference by others.

There are other less obvious aggravating factors in the declining health of our departments and I dwell on these in painting the picture as it now exists. The first is the inability of industry to identify and appreciate clearly the uniqueness of graduates from modern curricula in A&A. That uniqueness, as we faculty see it, lies in the fact that our graduates are well prepared in an understanding of the engineering sciences and have been introduced to potential applications to flight vehicle and other areas of high technology such as energy conversion and transmission. It is especially disturbing to students and faculty to observe recruiting announcements seemingly specifically excluding A&A graduates by identifying only M.E.'s, C.E.'s etc. while describing company interests which read like a copy of our curricula outlines.

A consequential problem has been the inability or hesitation on the part of industry to accurately identify a specific role for A&A graduates and to identify any selective retention of A&A graduates during lay-offs. The entering engineering student facing the need to select an engineering field of specialization frequently bases his choice on this sort of information - job availability and security - and it is a great discomfort for us to have to wax enthusiastic about both without any hard data or support from industry and, sometimes, government.

Another factor has been the inability of NASA to adequately sell the engineering aspects of its programs to the general public. The overrepresentation of the science of manned and unmanned space exploration programs has left to us in engineering education to elaborate on the engineering challenges and job opportunities within the NASA.

While the annual R&D expenditure nationally has maintained its level of $32 billion, the ratio between private industry and government spending level has been increasing. Private industries' addiction to stereotyping of engineering graduates has therefore led to the appearance of a declining job market for our graduates.

THE RESPONSE (Students and University)

Students, in general, began staying away from engineering and science during this time period under review. This has been especially true in A&A where the application potential of the stereotyped A&A graduate in solving current societal problems is not very apparent.

This has led university administrations to take a hard and suddenly cynical look at the staffing position in A&A departments, and in some cases, even the need for the retention of such departments. Since financial support of departmental operations is often geared to SCH (student credit hours) activity in state-supported universities, the support allocation to A&A departments, drawn from diminishing state support, has dropped to a mere trickle compared to the steady flow of just five years ago. Especially in publicly-supported institutions have there developed, in this same time period, increasing demands of accountability. Those bodies making the demands, state legislatures, state-level higher education coordination bodies, federal auditors, to name but a few, require responses in quantitative measures such as student credit hours per faculty member, graduate productivity, etc. A&A departments look especially bad at this time. They look to industry and government, and even the AIAA, for support and receive only general statements concerning the worth of all engineering in return. Even though it appears that the enrollment, and therefore the SCH, is again increasing, a definite statement of support from industry and government, possibly from this meeting, would be a welcome event indeed to A&A faculty.

OUR RESPONSE (A&A Departments)

To retain their member strength, and thereby program breadth and quality, faculty in A&A have been driven to undertake additional duties such as teaching lower-division courses or courses prepared to appeal to non-majors; to increase research or service activities; to take up opportunities for leave or to go on part-time appointments. Faculty in A&A are carrying on these holding actions because they remain convinced from their own observations of problems in high technology industries that the A&A graduate is a valuable professional. They would like a correction of this conviction if indeed it is false and the already-asked-for affirmation if it is not.

A&A faculty have begun intensive recruiting drives into high schools and junior colleges for young people interested in engineering careers in this field and associated technologies. In so doing one finds oneself spending considerable time explaining away the limitations of the departmental name. Consequently, the faculty have spent many hours debating the choice of more descriptive departmental names. This is especially appropriate in a department such as ours at Washington where about 50% of our research and graduate level courses are devoted to areas such as laser technology and applications, oil-spill spreading, applied mathematics, continuum mechanics, wave propogation, and ice-mechanics.

This broadened activity is quite typical of the stronger A&A departments across the country.

To offset the decline in operations support (equipment, supplies etc.), aggressive pursuit of surplused equipment is the order of the day. While increased research activity provides the specialized equipment, we are forced to depend on rebuilt cast-offs for commonly used research and instructional equipment. This is a frustrating procedure for equipment aquisition since all-too-often it turns out to be non-salvageable. The lack of any financial reserve for equipment replacement places our operations in a very exposed position. In this problem we also look to industry and government for help.

So the dilemma of departments of A&A is that while the faculty remain convinced that their graduates are viable professionals in an under-supplied market-place, they face administrations which doubt that claim. The lack of firm support from industry, government or the professional society makes the confrontation even more sensitive. Under these conditions many are assailed with doubts and we look hopefully to meetings such as this for reaffirmation of the worth of their labors.

PROPOSALS

1. Industry and government reaffirm the need for graduates from the type of programs specified by the ECPD, as directed by the AIAA, designated as aerospace, aeronautics and astronautics or by similar titles.
2. Industry and government identify the spectrum of job assignments for which A&A graduates are initially hired and indicate the expected job security in this particular company or laboratory activity.
3. NASA, in particular, and industry in general, assist in the preparation of definitive statements of the engineering career possibilities within their organizations and that this be presented in a form appealing to the high school and junior college age group.

4. Industry and government overcome the tendency to recruit our graduates as engineers stereotyped by departmental name. Most company recruiters still tend to think of our graduates as primarily equipped to assist in some aspect of configuring, powering, controlling and to adequately structure aircraft. It is simple fact that less than half our graduates are so specialized and inclined and that the majority are interested in other forms of high technology associated with aerospace.

5. Industry and government persuade university placement offices to refrain from accepting recruiting requests and announcements for engineers based on departmental diploma identification and that requests present, rather, job descriptions with the request that the placement office select qualified applicants for interview. I am assured by our placement office that they would prefer this system since they are in a position to recognize the extent of departmental and interdisciplinary programs extending beyond those boundaries associated with specific departmental titles such as C.E., M.E., A&A etc.

6. Industry and government recognize the need to break down the influence of professional societies in retaining the customary stereotyping of engineers according to degree titles and to support the current move to merge the major societies.

7. Industry and government increase their political support of engineering schools and the inclusion of A&A departments within those schools as they now imply through the definition of acceptable programs through the AIAA to the ECPD. If, on the other hand, such support cannot be readily given, then industry and government should clearly state the fact so that an orderly interment of A&A curricula can be begun.

8. Industry, government and universities somehow organize to analyze national needs for engineers covering not only numbers but areas of specialization and, possibly, universities which by virtue of faculty and location are best equipped to provide graduates in those fields of specialization.

9. Industry and government assist in the presentation to high-school-age students a true picture of the breadth and the excitement of our activities by opening up their places of business and reaching out to them in their classrooms through lectures and displays.

10. Industry, government and universities continue such mutually beneficial projects as temporary staff exchanges; on-the-job training for students; financial support for students; sharing of equipment and facilities; program planning; the creation of endowed chairs; the creation of chairs to be filled on limited terms by industry or government professionals; etc.

CONCLUSION

There are problems facing all departments of A&A, be they private or state supported, bearing many facets but resulting in the expected pressures from within our institutions toward programs which have tumbled from a forefront position in popularity and respect during the last four years. We are scarred but from our own analyses we remain convinced that we offer programs of merit and graduates of real value to the aerospace and associated high technology industries. We need your help in our beginning recovery into a planned development to a specified size and function. In this short paper I have indicated ten specific areas of need. Other university speakers in this conference will, I'm sure, identify even more. I sincerely hope that this discussion taking place now will lead to further meetings and the development of specific action plans.

SESSION II

TECHNICAL TRENDS IN AERONAUTICS

THE NEXT FORTY YEARS IN AVIATION

By Willis M. Hawkins
Lockheed Aircraft Corporation

INTRODUCTION

The explanation for the unusual "forty years" prediction in this discussion of the future is also a confession by the author that the paper is a sort of plagiarism. Ten years ago on the occasion of a meeting at the University of Michigan a prediction was compiled for a fifty year future, and since the environment today seems substantially depressed compared to ten years ago, it was felt that it might be useful to review the earlier prediction and to see how the industry had followed the prediction for the first ten years.

In any specific field where an effort is made to predict the progress of technology, it helps to define or predict the environment within which this progress will be made. Trying to predict what is likely to happen in the field of aviation is no different, and, accordingly, a series of assumptions should be made to make the predictions for the next forty years sound reasonable.

The first assumption is that the state of the art in international relations will, hopefully, not explode in major conflict and that the nations of the world will attempt to trade with one another in much the same way as they are trading today, hopefully to include the whole world.

Secondly, it seems reasonable to make the assumption that the change in population will be reasonably normal and that the economic growth of nations will continue to be progressive.

I propose to place numbers on these assumptions. I then propose to look at aviation in several major categories: general aviation, short-range transport, long-range transport, and finally, I propose to make a few suggestions on the future of military aircraft -- all based on the economic and population growth which I have assumed.

This is 1974 and the paper was originally delivered in 1964; thus 20% of the time has passed to the year 2014. The author hopes that someone will ask him to look again ten years hence.

BASIC ASSUMPTIONS

Several references have been reviewed in an effort to build a foundation for the growth of aviation, and, as a result of this study, some predictions have been made regarding the growth of the United States in population, the growth of the Gross National Product within the United States, and the growth of the number of wage earners. The reason for attempting to define this environment is obvious, since the Gross National Product is a reasonable acceptable measure of most commerce and since the availability of excess income over subsistence by the wage earner is the foundation for new fields of economic and technical development.

Figure 1 summarizes the assumptions that were being made in order to study the potential of aviation. It appeared from the references used that the population of the United States would grow in such a manner that by the year 2014 there will be approximately 420 to 450 million people in the United States. On figure 1 a new check point has been added. The U.S. population only grew at a rate of 1.1% from 1964 to 1973 and predictions of growth rates between .7% to 1.2% are now the norm and, thus, the new estimate for 2014 shown on Figure 1.

There are those who feel that a Gross National Product proportionate to population growth is probably all we can expect and there are others who feel that it should be possible to achieve a growth rate of approximately 6% per year.

Since this paper does not presume to make any major contributions in terms

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of the economic future of the U.S., but is only seeking to find some kind of base upon which to conjecture the growth of a very specialized technical area, it has been assumed that a moderate 4 percent per year expansion of our Gross National Product will be achieved during the next forty years. This estimate has been retained in this second look but the value at the year 2014 has been expanded to a band the bottom of which reflects the % reduction of GNP that corresponds to the % difference shown in the population figures at the year 2014.

Several implications are immediately apparent if the combination of population and GNP is studied. One is the fact that in 1964, if the GNP had been distributed to each of the individuals in the U.S., the average would have been approximately $3,130 per person per year. If the wage earners are assumed to be approximately 70 million today, this distribution of GNP turns out to be approximately $8,550 per wage earner. It is probably not necessary to determine whether this is, in fact, real income; it only serves as a basis for future conjectures, and these conjectures, if translated into the year 2014, show that our GNP at that time will be between $16,400 and $28,200 per wage earner. If we now repeat this exercise with the 1974 prediction we obtain a spread of $25,200 to $32,400 per wage earner.

As shown in Figure 1, the reason that the ratio between the GNP per person and the GNP per wage earner does not stay constant between the two extremes is that inherent in the prediction of GNP is the fact that there must be either a higher percentage of wage earners in the population to produce the increase in GNP above the population increase or that the efficiency of each wage earner must change in a major way.

Finally, since practically every economist is predicting a shortened work week in the future, the number of wage earners must go up even more to account for the fact that each of them will produce fewer man hours per year. In this particular case it has been assumed that three hours per week will be added to a wage earner's leisure time by 1976 and that eight hours per week will be added to the leisure time by the year 2000. This prediction seems invalid in 1974 since the average weekly hours only decreased .6 hour between 1964 and 1973 which would produce only three less hours/week in the year 2000.

In order to emphasize some of the points of Figure 1, a summary for selected years during the next forty is shown in Table I. Listed are the Leisure Hours per Wage Earner and the Extra GNP produced per wage earner over that available today. It is reasonably obvious that if the U.S. economy and population both increase as assumed, we will indeed have a substantial augmentation in the amount of time and money which can be counted on to induce an increase in travel, some of which certainly must benefit the aviation industry. The corrections for the new 1974 view of the future are outlined in boxes on Table I.

GENERAL AVIATION

Very few members of the aviation industry have published estimates on the future of any particular element in aviation other than those published by the Federal Aviation Agency. As these extend only to 1970 or 1975, it has been necessary to do some numerical conjecturing beyond that point.

Figure 2 shows three curves which are extensions of the FAA predictions covering the multi-engine general aircraft, the so-called private aircraft (one-engine, four-place, and over), and rotor craft. It will be noted that an increase of four percent per year has been assumed for all of these classes. This four percent prediction is somewhat lower than that projected by the FAA up to and including 1975. Even this reasonably conservative forecast produces some rather startling numbers for the year 2014. For instance, by this method it is predicted that there will be 80,000 multi-engine general aircraft flying and that traffic systems will have to accommodate 260,000 one-engine, four-place aircraft. This means a total population of 340,000 general aviation aircraft.

This is not an improbable number if compared to the probable population of automobiles which could reach over 150 million by 2014. There are limits, however, and it is obvious that technology could delay the onset of these limits, in both the executive and private owner markets.

What then is needed in the executive market. I suggest that the following characteristics are reasonably obvious and should form the basis for future development.

1. Quiet vertical take-off and landing capabilities.
2. Multi-engine safety in the take-off and landing maneuver.
3. Precision landing and take-off aids for minimum visibility operation in a multiplicity of areas -- primarily roof tops in cities and industrial areas.

It is probable that the executive market can, indeed, borrow from a larger market the developments which will produce the above characteristics; however, this borrowing is dependent upon the development of similar characteristics for an entirely new commercial market. This will be suggested later.

More challenging than the executive field is the field of private owner aircraft which generally cannot rely on any parallel field for its development. Furthermore, expansion up to 260,000 registered aircraft cannot possibly take place if private aircraft utility does not increase in a major way. Therefore, we should look closely at the following performance specifications to determine whether or not it will be technically possible to produce an airplane to attract such a market.

1. In parallel with the executive transport, it is necessary to have quiet VTOL characteristics.
2. Multi-engine safety for take-off and landing will be essential.
3. Simplicity of flight and navigation must be improved.
4. A universal system that provides for enroute emergencies and traffic control must be developed.

This is a large order; however, an increase of between $8,000 and $19,000 of GNP per wage earner per year ($15,000 and $22,000 by 1974 estimate) and an increase by 50 days per year in the wage earner's available free time (27 by 1974 estimate) will certainly produce a market if a reasonably priced transportation package can be produced.

Several suggestions are worthy of detailed study.

1. If quiet VTOL can, indeed, be obtained with multi-engine safety for take-off and landing, roof-top centers should be acceptable to most commuters and it would appear that some type of business community concentration may be both desirable and necessary for the use of such a product.
2. It is my personal opinion that an all-weather navigational system which attempts to guide a man directly to his home with an aerial vehicle is much too complicated to consider and we will, therefore, have to assume that he keeps his aircraft in a community center garage where facilities for landing and take-off, particularly the navigation, are made available. This facility, as will be discussed later, may also provide the community a central station for "less executive" commuting and shopping traffic.
3. The United States and all of its cities are crisscrossed by telephone wires or power systems. If these wires could carry a coded signal and the private airplane could have a "wire follower", perhaps a partially-made navigation system is now in existence.

If this technical order sounds difficult, industry should be spurred by the fact that producing these vehicles alone represents a potential gross income of over $5 billion for someone.

Already by 1972 the author underestimated the market by 10,000 units, a growth rate of 6%. This does not sound like a depressed industry. But it is the author's belief that such an expansion will not continue unless major changes in utility occur.

SHORT-RANGE AVIATION

By previous standards, short-range aviation has generally been assumed to be that type of transport that involves intercity traffic between small cities with trip distances up to 300 miles. This type of business constituted approximately 2.56 billion passenger miles in 1964 (9.48 in 1970) which was 9.3

percent (8.7 percent in 1970) of 1964 total commercial traffic. In spite of the fact that this percentage is reasonably low, the problems of serving these passenger miles and the generally accepted conviction that many more passenger miles are available have caused a multitude of designs to be created to better fulfill this requirement. So far, with only marginal improvements in technical capability, short-range services have had to be subsidized and short-range helicopter feeder lines, although progressing gradually, have not shown any signs of creating a vast, new pool of customers.

Before we conjecture further in this field, it should be recognized that the short-range passenger has a basic decision to make and this decision is whether or not it is worth the trouble to seek out an airplane and get on board since a disproportionately greater amount of time is spent in getting to and from the airplane than in flight.

Figure 3 summarizes some of the effects of time on block speed and several points are worth picking off this curve to illustrate this critical problem.

If a 100-mile trip is taken by an airplane and it requires an hour and a half to get to and return from the point of embarkation and if it takes a further 20 minutes to check in and board the aircraft and 10 minutes to clear the aircraft in and out of traffic, the actual block speed attained by a passenger on a 300-mile-an-hour airplane is only 40 miles an hour. This is little, if any, better than a passenger can make in an automobile for the 100 miles, and it is not enough better to be at all attractive if he must handle baggage, buy tickets, and, in fact, spend more money than if he had taken his car.

Thus, it is relatively obvious that a major change would be made in the available customers if vertical take-off and landing capabilities could be given to the short-range aircraft in order to bring the airline terminal to the customer at least on one end of the trip. Such a separate terminal could, hopefully, also reduce the traffic problems of the airplane, since there would be many more individual terminals separated from one another.

Referring again to Figure 3, if a saving of one hour could be made in the handling of passengers, traffic control, and the driving to and from the point of embarkation, a change in block speed for a 100-mile flight could be improved to 75 miles per hour without changing the cruising speed of the airplane whatsoever.

While discussing short-range aircraft, it would be well to consider the fact that an aircraft designed to improve service to the short haul transportation market might, if done well enough, attract an entirely different category of passengers, the commuters. There are millions now and their number will be growing substantially within the next forty years.

Figure 4 has been prepared only to illustrate the characteristics of these customers. In this illustration, a plot is made of a "tolerable" distance between one's living area and one's work, if these commuters are willing to spend one hour of their time getting to work. It may be argued that two hours per day is too much time to spend in the process of travelling to and from work, but it should be remembered that a substantial portion of today's workers do spend this amount of time; and, if this time can be spent without the responsibility of driving or navigating and could be spent reading one's newspapers or reading for relaxation, it would be time otherwise spent statically and would not be a total loss. The surprising part of Figure 4 is the fact that a good commuter aircraft system (which would permit the commuter to live over 100 miles from work) opens up many possible living areas that might easily cause a wage earner to spend a substantially greater portion of his wages and time on his transportation to work. Since the cost of this long-range commuting is only a little more than a very short-range "chauffeur" drive it is possible that the first air commuter service could be a cooperative executive charter from a remote "country club" community.

It would appear, therefore, that a major challenge exists in the area of short-range transport since an aircraft with suitable characteristics might serve one slowly developing market and might tap a vast market that is entirely new to the aircraft industry.

Figure 5 makes an effort to show how big this new commuter travel market might be. Starting from the wage earner population shown on Figure 1 (repeated in more detail on Figure 5), another conjectural curve has been created. This is the curve labeled "Wage Earner Travel Miles Per Year, " based on only that mileage required to get to and from work. Assuming a very modest increase in the distance to and from work between today's average of four miles and an estimated average of approximately eight miles 50 years hence, it is estimated that there will be 805 billion passenger miles travelled going to and from the wage earner's place of business. If only one percent of this business could be acquired by an aircraft system, this would support 1400 aircraft operating at an approximate 50 percent load factor. (The airplane assumed has a 60-passenger capacity, cruises at 200 mph or over, and is assumed to be used only 1000 hours per year for commuter service.)

It is worth noting when considering such a number of passenger miles, that the number of registered automobiles is estimated by some to reach 172 million in this time period. Assuming that only 67 percent of these cars are used for going to and from work (approximately the same as 1964), it would appear that 75 billion worker miles are not covered by automobiles and must be supplied by either additional passenger occupancy of automobiles, by going to and from work on foot, high-speed mass transportation systems, etc. Certainly this is a pool of business that the aircraft industry must not ignore. The one percent of total worker-travel miles previously mentioned is approximately 10 percent of this excess of travel miles required. Even this small percentage is $2 billion worth of business in producing the transport vehicles, and, on the basis of 5¢ per passenger mile, it is approximately $400,000,000 worth of business per year.

Augmenting this business is the normal business that might be expected from the same type of aircraft in intercity service within the range of 100 to 500 miles. In this service it is obvious that its speed would not be limited to 200 mph and since a VTOL aircraft inherently has power for higher speed it can be assumed that en route velocities of 400 to 500 mph are readily attainable. As shown previously (Figure 3), it is more important to land and take off close to the traveler's destination than to achieve high speeds; therefore, here as with the commuter, the ability to serve roof tops and quiet communities is the predominant requirement rather than cruise speed.

The 1974 look at this short-range market potential is little if any different than 1964. Unfortunately, subsidation of short-range surface travel, largely hidden and habit forming, keeps "mass transport" mired in the earth's surface. It is this author's conviction that a good subject for a university investigation would be the determination of real subsidies to surface transport (Bart in San Francisco) and the conjectural-technical contemplation of what could have been done with the same money in creating an aerial system.

DOMESTIC TRAVEL

Figure 6 combines both the medium and long haul domestic travel in an approximate way only to show the probable range of total business. As shown on Figure 6, it is estimated that almost 90 billion passenger seat miles will be available to the travelling public when presently ordered aircraft are in service in 1966. In Figure 6 two estimates of future passenger markets are shown based on a two percent growth and a four percent growth per year of passenger miles.

Since the domestic routes in the United States represent the most highly developed airway system in the world and since the airline operators have now moved almost all the way to low cost coach operations and since they are already beset by many community problems (noise, traffic, etc.), it is difficult to predict a growth much higher than two percent unless some change is made in the system itself.

In this total field the 1964 estimates were seriously conservative. 1973 results exceed predictions by 25-30% in spite of the so-called depression. As shown on Figure 6 there are some who predict a further fourfold increase by the year 2000.

Turning back to the short-range portion of trunk travel we see that limitations might be lifted by the same aeronautical advances that could bring the commuter and shuttle type passengers into the air travel habit. Thus, again, we are faced with a requirement for the best possible transport that can be a good neighbor in city centers or small communities. Figure 7 has been included to show two concepts of many that have most of the elements which might be included in such a transport. In both designs the downwash velocity is relatively low in vertical flight promising a reasonably simple platform for take-off and landing. Furthermore, both designs offer some chance of having a reasonably low noise level during the time that they operate close to the ground.

Figure 8 summarizes the noise problems as seen by the Helicopter Council where it is shown that present helicopters with no particular attention paid to noise are nearly at the low level of noise which should be acceptable to a community. Shown also on the curve is the noise problem of a normal jet airplane illustrating why they must live at long distances from their potential customers.

Combining the problems suggested by the noise summary of Figure 8 with the advantage of terminal time saved as shown in Figure 3, it seems reasonably obvious that airplane designs similar to those shown on Figure 7 would be worthwhile to contemplate, even if some penalty in today's cruise speed were accepted. Two points on Figure 3 serve to emphasize this; at the 500-mile range, an hour saved at the terminals is worth over 200 mph in cruising speed and even at the 1000-mile range, one can afford to pay 150 miles for an hour saved at the terminals.

Since there is no obvious reason why such large speed penalties are inherent in the designs of Figure 7, it seems reasonable to assume that the short-range portion of our domestic traffic could be assumed to grow by acquiring new customers over and above population growth. Assuming a four percent growth in this area has the results shown in Table II.

Revisions based on the last ten years show that there is a manufacturing potential of $8 billion or more and an operating market of $8 billion to $9 billion per year. (See numbers in boxes on Table II.)

Beyond the short-range portion of this potential future is the more normal trunk traffic now being served by the large jet aircraft. As shown on Figure 6, the total market was at the level of 40 billion passenger miles in 1964 including the short-range portion just analyzed. One can assume that our current pattern will not change and that a normal progression to larger and more economical aircraft will emerge. These results are shown for the year 2014 on Figure 6.

If it is assumed, however, that the short-range market moves as shown on Table II and that the long-range portion progresses at a four percent rate as demonstrated in the last ten years, we can calculate a total long-range market as shown on Table III. The 1973 revision of this potential produces an astonishing 1120 aircraft corresponding to a $20 plus billion manufacturing work load and a $21.5 billion annual passenger carrying opportunity. (See boxes on Table III.)

In summary, the domestic traffic market for the new airplanes and services, although estimated to increase less rapidly than other aircraft categories, is still attractive business and a new idea or two in the quiet, efficient VTOL field will not only open up a vast new customer area, it will also give a mighty boost to the short haul portion of the domestic travel segment of the business.

INTERNATIONAL TRAVEL

The character of the work week in the year 2014, as previously mentioned, will, in all probability, be such that three-day weekends will be frequent and, furthermore, the work year will contain major periods of vacation. Finally, the "sabbatical" every few years will, hopefully, extend several months. This leisure or educational time cannot help but expand international travel if supported by added excess income. Thus, if Table I is valid, the world of international travel is in for expansion that should brighten the eye of almost everyone in the air transport industry.

Figure 9 attempts to show the extent of this potential by plotting the familiar revenue passenger miles versus years -- this time using both the previously assumed four percent per year expansion and also a five percent estimate to account for this author's optimism for the potential of international travel.

Here, the 1964 estimate was seriously in error. As shown on Figure 9, 1973 should have produced 30 billion passenger miles. 1973 did produce 87 billion passenger miles, almost three times the estimate (37 billion passenger miles on U. S. airlines and 50 billion on foreign airlines).

For those contemplating the future of the Supersonic Transport, it was decided to emphasize the year 2014 potential by estimating the numbers of supersonic transports required to fulfill this expanding market. The numbers of aircraft appear to be small compared to other types of aircraft previously considered for domestic traffic, but it should be remembered that the Supersonic Transport is a powerful producer, delivering 386 million revenue passenger miles per year at 60 percent load factor (100% = 150 passengers), 2000 miles per hour, and six hours per day utilization.

It is probable that some development of today's supersonic aircraft will, indeed, be the international carrier in 2014, but the technology is moving so fast that it might be well to pause for a moment and contemplate other approaches to this market. Figure 10 is an effort to compare, visually, several alternates. All inboard profiles are of the same scale for the purpose of comparing volume, length, etc., with a "typical" supersonic transport.

The "Standard Economy" Aircraft

On Figure 9 an aircraft with 200 passenger seats was listed because it could be contemplated as a conservative extension of our present international transports. This type of aircraft could be a competitor in the year 2014. It could produce lower cost seat miles and since Europe is now only a "meal and a movie away" the Supersonic Transport may well force the passenger to choose between a movie or a meal. To pay extra and still make such a choice may not seem worthwhile to many who have a month to spend, and who think movies and refreshment en route are indispensable.

Figure 10 carries this philosophy further in an effort to see if a Subsonic Transport could reasonably be considered which had the same annual "production" capacity as the Supersonic Transport in spite of nearly 1500 miles per hour cruise speed difference. The surprising result is that an aircraft large enough for the required 490 passengers is not as long as the Supersonic Transport and, comparing it with a "typical" Supersonic Transport, it has approximately half the wing area. Thus, it must be assumed that a large, truly "liner" variety of aircraft could be produced, at a substantially lower first cost and a much lower operating seat mile cost than the Supersonic Transport for the same annual productivity of seat miles. Finally, the development risk and time span should be reduced substantially in comparison to the Supersonic Transport.

It is obvious that the 1964 suggestion had some validity since the 747 has come into being and is now a mainstay of the international traffic system.

The "Semi-Ballistic" Transport

Unfortunately for those who are about to accept the responsibility for Supersonic Transport decisions both in and out of government, the large subsonic aircraft is not the only competitor. On Figure 10 it is suggested that our space endeavors have eliminated one by one most of the major objections to man flying in the upper atmosphere or out of it and with another fifty years of effort behind us it would be technically reactionary not to admit the possibility of ballistic passenger transports. In order to illustrate the point, only one suggestion has been presented (with suspiciously few details). In this system it is contemplated that the ballistic transport is headed in approximately the same direction. Thus the "first class" traveller is afforded not only superior service and a separate cabin but also a faster transit time. Cursory as this view has been we have too many tools with which to do a system of this sort to ignore it.

Finally, on Figure 10 another variation of the ballistic transport is offered. In principle, it is to be launched in the same manner as the larger aircraft -- it only differs in the class of service offered to the passengers. I will leave it to the reader to decide whether this is a "golden carpet" service or "steerage." The essence of this concept is the possibility of an acceptable sleep machine. These devices, which have been scientifically demonstrated, could be contemplated as reliable sleep producers which only fail upon loss of power and could be counted on to permit full wakefulness on the cessation of power. To carry this concept further the passenger arrives at the terminal, enters an attractive roomette, lies down with his baggage beside him, clamps on his head set, and is immediately in a sound sleep. The crew gathers his baggage, zips his full length "safety belt" (a head-to-toe nylon net) and the passenger is "stored" on board within a minimum space -- oriented to take load factors in the optimum way. He is awakened by power turn-off in a similar roomette at his destination -- refreshed -- with his baggage beside him and immediately available. He has remained totally unconscious of any noise, load factors, or minor discomforts.

Whether or not this appeals immediately to a "first time" passenger, it is obvious that the space saved (and weight and drag) would be very welcome in the design of any system, ballistic or not. For the every day or every week traveller, the idea has few terrors -- one has only to remember that many would much prefer to pay the extra dollar (two dollars in 1974) for a "sleep" head set than for an earphone for the movies.

It is not clear to the author that the previous predictions are better or worse than he would make in 1974. The state of the hypersonic art -- the potential, if not the inevitability, of hydrogen as a fuel and cooling medium -- all suggest that a Mach 6 transport with a range equal to half the world's circumference is entirely feasible. This is a formidable competitor to any ballistic transport and the propulsion system has the capability for "self takeoff" which simplifies the system. Today, 1974, the author favors the hypersonic, hydrogen powered concept.

AIR CARGO

Air cargo has for many years appeared to be just on the verge of explosion and today (even 1974) is no different. It has always been said that the "next" airplane will lower the cost per ton mile drastically and start a flood. Looking at the recent experience in the United States and attempting to extrapolate it on the basis of history would describe just such a flood. In the following table we see this history in terms of percent increase in revenue cargo ton miles over several previous years:

Recent History of Air Cargo

Increase in Percent of Revenue Ton Miles over Previous Year

Year	Domestic	International	Total
1958	2%	-2%	1%
1959	15%	15%	15%
1960	11%	-3%	7%
1961	14%	27%	18%
1962	33%	40%	35%

If we take 1962 as a base with its 1.6 billion revenue ton miles of international and domestic freight and express and if we take a hypothetical 80,000 pound payload cargo transport operating at 60 percent load factor at 500 miles per hour with 10 hours per day utilization, only 38 airplanes would be required. This points up the fact that the business is not yet large enough to form a statistical base and it would be extremely dangerous even to conjecture on the expansion of the last few years.

One thing can be done, however -- we can take our recent experience as a sure base for optimism and look at the problems facing the cargo operator to see if ingenuity on the developer's part can prevent this market from being limited in the future.

1. Low cost operations imply large payloads. Railroads can couple cars together, but ships and aircraft must be loaded. Can aircraft loading be rapid enough to keep the airplane flying? (Maintain high utilization)
2. Rapid distribution must follow rapid transit. Can terminals and ground transport match a rapid expansion?
3. With demands for rapid loading and unloading, can the tare weight on cargo be kept below present levels to maintain low cost per ton mile?
4. Can air cargo hope to reach far into the ship and rail business without major storage facilities at the terminals? Aircraft cannot sit on sidings or tie up to piers and hope to compete.

Of the various new ideas beginning to appear for cargo air traffic, the most attractive appears to be the close-to-surface, low aspect ratio, low speed (200 miles per hour), transport. Some theorists predict L/D ratios approaching 40 if techniques can be developed for flying close enough to the surface to be measured in fractions of the wing chord. This is a large technical order when surface conditions force an average altitude of at least 50 feet thus dictating chord lengths in the vicinity of 200 feet. This translated into usable designs implies payloads approaching a million pounds and airplane weights of nearly that much. Other conjectures suggest sizes well over double this amount. It is obvious that the main problem for vehicles of this description has to do with creation of the first one. It would be convenient if there were an obvious trade route of high cargo potential that was entirely over water that never had wave heights of over three feet. For that route one could consider a modest size prototype system. As of this writing no such route appears to exist.

The 1974 look is little, if any, different. In 1972, 14.2 billion revenue ton miles were carried, over 9 times the 1962 performance. Even so, this was hardly enough to attract the attention of those who carry surface freight. Today we can carry cargo with lighter densities than approximately 15#/cu.ft. cheaper than container ships and this is over half the cargo carried by these ships. Why isn't this a major business?

The fact, apparently, is that there is no way to finance the growing pains of such a system. The start up costs are beyond comprehension and the airlines have no reserve for such ventures. It is worth suggesting that a government sponsored cargo line connecting two (or ten) high cargo potential airports (international) using hydrogen powered versions of existing transports might produce the following:

1. An entirely new market for transport services and aircraft.
2. An operationally confirmed system for employing hydrogen as a fuel.
3. A rejuvenation of the United States posture as the world's leading transporter of goods. (The Clipper Fleet revisited.)

MILITARY AIRCRAFT

Predicting the future of military aircraft during peacetime may depend in some way on the growing economy of a nation but the dependence is not obvious since any estimate for the next 50 years of military spending, even if it were predictable, would not contain a logical, defined element called aviation.

One trend is reasonably clear, however, and it may permit the military and civilian aviation expenditures to be more mutually helpful than they have been in the past. This trend is toward the use of aircraft more in the utility role than in the weapons role. Future military planning in times of peace -- particularly the kind of unstable peace we are now experiencing -- generally reverts to the contemplation of crisis areas and the planning for conflict in those areas. For the United States this means logistics planning.

Even in a local area, the worth of the airplane as a logistic tool has begun to emerge since most of the actual or potential fields of conflict are in the undeveloped areas of the world where the only logistics or communications system that can be installed without large capital expenditures and long lead times is an aircraft system.

Rather than attempt any prediction about future military aircraft to aviation, it might be profitable to list some problem areas that are inhibiting development. Here, as in the cargo aircraft areas any solution may spark rapid expansion -- sometimes only in specialized areas -- but other times in the entire field. Notable in this list is the absence of air frame problems -- this is an historic pattern in the aircraft industry and one that is apparently continuing. The technical items limiting expansion are generally exterior to the air frame.

Navigation

Military aircraft have always been limited in utility because of lack of valid maps -- known landmarks and the fact that very few missions are repetitious. Navigational schemes of relatively short range to support reconnaissance and follow-on strikes, to support the use of aircraft as command centers, and to serve as "get-home" aids on missions of opportunity and in emergency are needed. We have ideas but all of them are expensive to buy and are not reliable with the maintenance that can be provided by a forward unit.

Communications and Traffic Control

Military missions can profit very little from the very successful development of the civilian communications and traffic system. The environment of military air is such that almost all such systems must be self-contained, or at least air transportable and immediately operational at deployment. As a result of having no large base on which to build, the solutions in this area have been cumbersome at best and useless in too many cases.

It is hoped that many of our space borne experiments may help in both the navigation and communications fields. Space borne computers, wide band data links, and lightweight power supplies should be applicable before too many years have passed. (1974 has rewarded this suggestion amply -- we seem to be using our talents well.)

Night Vision

For many years the problem of presenting information acquired by sophisticated data gathering systems in such a way that it simulated direct vision has preoccupied major developers. Large strides have been made, but complexity is still extreme and the presentations very limited. Constantly supplementing these efforts have been the direct vision efforts starting with searchlights and culminating in recent years in systems using "non-visual" illumination coupled with conversion sighting systems which make the non-visual visible to the equipped operators. Finally, light augmentation schemes have begun to show promise and it is hoped that soon we will be able to operate with limited direct vision.

Military advantages for such a system are obvious: surveillance, direct target attack, local navigation, and night operations with covert bases. (Here again 1974 showed major fulfillment of progress.)

Lost Cost, Quiet, VTOL

Although the achievement of many forms of VTOL is one of the dramatic accomplishments of recent years, there have been very few of these types of aircraft accepted for actual operation over and above the straight helicopter. Where VTOL has been essential, the cost of the helicopter to purchase and its high operational costs have dwindled into insignificance in the face of the new capabilities added to the services by the VTOL feature. It should also be noted that the pure helicopter has improved impressively in operating efficiency and cost.

Whenever there are only marginal advantages for VTOL, the more normal aircraft usually wins because of its high ton mile per day production, its high utilization per day, and its low operating cost. The fact remains that every task an airplane performs should be benefited by a VTOL capability. As soon as this can be obtained with reasonable economy such aircraft will be universally adopted.

Unique in the field of requests for aircraft designs for the military is a new request from the Army that contains noise level criteria for the vertical takeoff and hovering mode. The military usefulness of this is contained in Army experience where very slow flying and hovering aircraft have been found extremely difficult to see and, if there is no warning, maneuvers can be accomplished before the enemy is aware of the aircraft's presence. For a high or moderate speed airplane at low altitude the airplane usually precedes any coherent warning noise. (Turbo props are particularly good at low altitudes.) For a helicopter, however, there is little or no speed to reduce the exposure time; therefore, the requirement for very low noise becomes predominant.

Here is obviously a program which could complement or lead a commercial program since VTOL, with economy and low noise, is the foundation upon which any new short-haul commercial market will develop. For the sake of both the military and civilian operators, I hope the solution of this problem is soon.

With no attempt at humility, the author couldn't have said it better in 1974 than he did in 1964. The only trouble is that nothing has happened between 1964 and 1974 that can be called progress. Here is an area of challenge that needs both technical and financial (political) champions (on the same side.)

CONCLUSIONS

Taking a broad look at all the fields of aviation that have been covered, we can conclude that there will certainly be a market for aviation products and there will be an even bigger market in terms of airline travel. If we, in fact, add up the total dollars for air frames that must be purchased to handle this traffic in the year 2014, it totals approximately $26 billion. ($76 billion using 1973 as a base.) For that portion of this equipment that is utilized in transporting people, it has been conjectured that the market could be $36 billion per year in revenue passenger miles. ($81.5 billion based on 1973.) This harvest will not be reaped without major technical strides within the industry.

Figure 11 is an effort to place on one chart a summary of all the commercial fields that have been discussed in order to point up the technical challenge that exists.

In the lower end of the range between 20 and 300 miles, the primary challenge which faces the industry is the challenge of vertical rising, quiet aircraft that no longer have the characteristics of stunt machines but have reached the maturity of real transport vehicles. At the lower ranges between 20 and 100 miles the costs per available seat mile will have to be one-third to one-fourth of the cost presently being experienced by our best vertical rising machines today (1964 or 1974) and the vehicle will have to be in every sense a good neighbor. This means that it will have to operate safely in highly populated areas without imposing crash hazards and without increasing the ambient noise. In a small community that ambient noise will certainly be a major challenge.

Extending this, or similar machines, out to ranges of 300 miles suggests that the competition with conventional aircraft may be somewhat more difficult to meet. The airlines today offer shuttle service at a cost that is attracting many new customers. Here, again, a quiet, vertical rising and landing airplane with velocities in the neighborhood of 300 to 400 miles per hour can have these customers and a multitude more, but the added multitude will not exist unless the machine serves the centers of population rather than the fringes.

Even at ranges above 1,000 miles, we cannot ignore the advantages that accrue to takeoff and landing operations close to population centers. It is worth considering that flight routes of 1,000 to 1,500 miles may more expeditiously be served by vertical rising airplanes with modest cruising speeds (between 400 and 500 miles per hour) as long as they are quiet and safe enough to operate close to the center of communities and as long as these characteristics can be obtained while simultaneously reducing the cost per seat mile to that of our present airline shuttles.

In Figure 11, stepping out to 3,000 or 4,000 miles, the problem becomes more complex. It is not entirely clear that conventional landing and takeoff will be superseded at all ranges if, in the future, a high average speed for the conventional airplane can be maintained. It is reasonably obvious that the major problem to be faced by the supersonic transport is noise (1974 confirms the 1964 statement). This noise problem extends all the way from takeoff to destination; and, if altitude alone won't solve this problem, it is entirely possible that the long-range transports of the future will take on an entirely different form, perhaps involving carrying capacities approaching 500 passengers (1974 has confirmed this prediction). In this range regime, a very severe challenge exists to somehow solve the en route noise problem of supersonic transports.

One obvious solution is, of course, the ballistic transport bringing with it additional problems. If our space programs can be maintained at the current levels and if our successes continue in this field, I would like to suggest that the ballistic transport may, indeed, be the best solution for high speed, long-range operations.

The one singular conclusion that can be drawn is that the challenge of the next forty years may be of an entirely different character than it has been for the last fifty years during which miracles have been produced in increasing velocity, capacity, and economy simultaneously.

We appear to have a choice to make in continuing the race toward more speed. The airplane is becoming less socially acceptable at its terminals and it is not clear that additional economies are certain to be obtained.

On the other hand, if we were to retain our present operating speeds and look back to those problems of terminal operations which make the airplane a good neighbor in the centers of our cities, we might tap an entirely new element of our population. If these predictions are even approximately correct, millions of new passengers are about to enter the market. They will have both the opportunity and money to fly. With the proper service they will want to fly often and everywhere.

Added to these 1964 conclusions (in 1974) is the conviction that we should begin explorations in the use of hydrogen fuel. Hydrogen improves operating economies (see suggestions on a model subsonic cargo fleet); improves, by a wide margin, the impact of aircraft on the atmosphere; and makes possible the contemplation of a hydrogen powered hypersonic transport with "half way round the world" range potential. The United States should move solidly in this field.

TABLE I

Significant Time and Money Available for Leisure or Cultural Activities

Year	Extra GNP per Worker		Extra Leisure over 1964	
	Minimum Wage Earners*	Maximum Wage Earners*	Hours per Week	Extra Days per Year
1974	ACTUAL 10,500			
1976	13,120	11,060	3	19
1990	15,500	11,700	6	38
2000	20,000	13,300	8	50
2014	28,200	16,400	8	50
2014	32,400	25,200	4.2	27
	NEW ESTIMATE			

*Based on the minimum and maximum number of wage earners shown on Figure 1 (no inflation).

TABLE II

Short-Range
Domestic Travel Growth Conjecture

1961 Actual Passenger Miles (trips under 700 miles)*	8.4 Billion
ACTUAL 1970	31.8 BILLION
Estimated Passenger Mile (Revenue) in Year 2014 at 4 percent per Year	67.4 Billion 176 BILLION
Required Airplanes (60 percent load factor, 60 passengers, 400 mph, 4260 hours per year)	1100 Airplanes 2900 AIRPLANES
Dollars Business in Manufacturing Airplanes (3 million per airplane)	3.3 Billion 8.7 BILLION
Dollars Business at 5¢ per Passenger Mile (per year)	3.37 Billion 8.88 BILLION

*CAB 1962 Edition: Handbook of Airline Statistics

TABLE III

Long-Range
Domestic Travel Growth Estimate

1964 Estimated Travel over 700 Miles (Revenue Passenger Miles)	30 Billion
1970 ACTUAL	76.6 BILLION
2014 Revenue Passenger Miles (at 2 Percent per Year Increase)	90 Billion
AT 4% PER YR. FROM 1970	430 BILLION
Number of Airplanes (60 Percent L. F., 150 Passengers, 500 MPH, 4260 Hours per Year)	470 Airplanes
WITH 300 PASS. AIRCRAFT	1120 AIRPLANES
Dollars Business in Manufacturing (at $9 Million per Airplane)	4.2 Billion 20.2 BILLION
Dollars Business (at 5¢ per Passenger Mile per Year)	4.5 Billion 21.5 BILLION

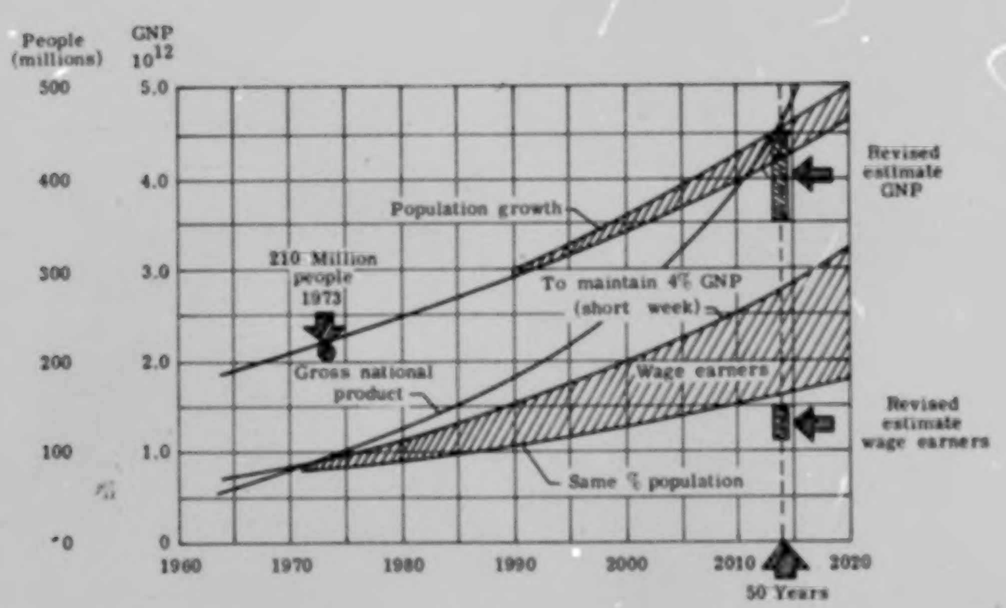
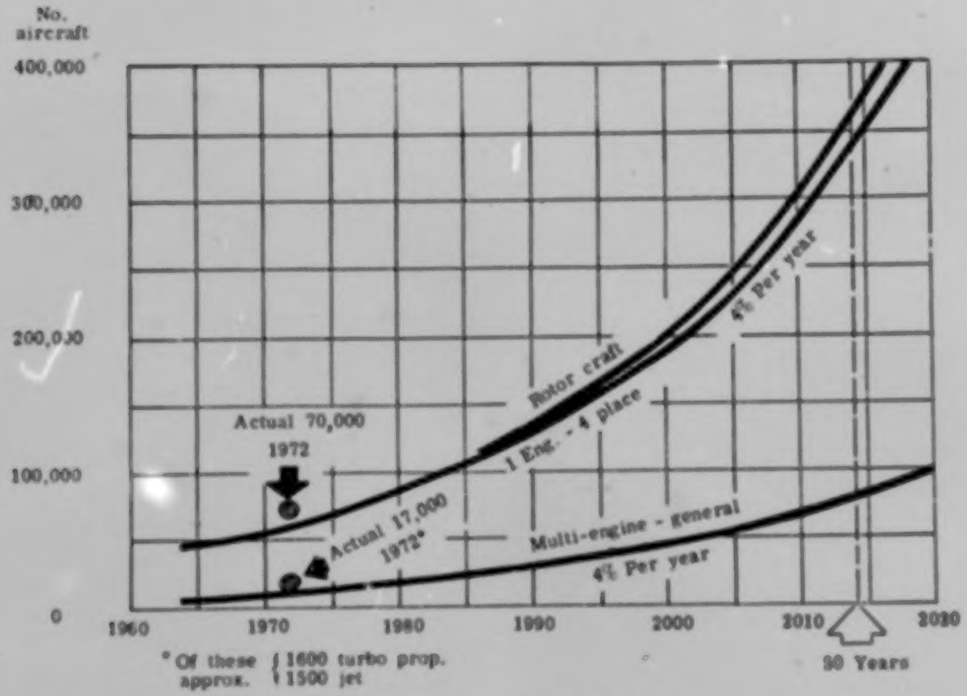


Figure 1.- Population and economy growth.



* Of these approx. {1600 turbo prop. 1500 jet

Figure 2.- General aviation.

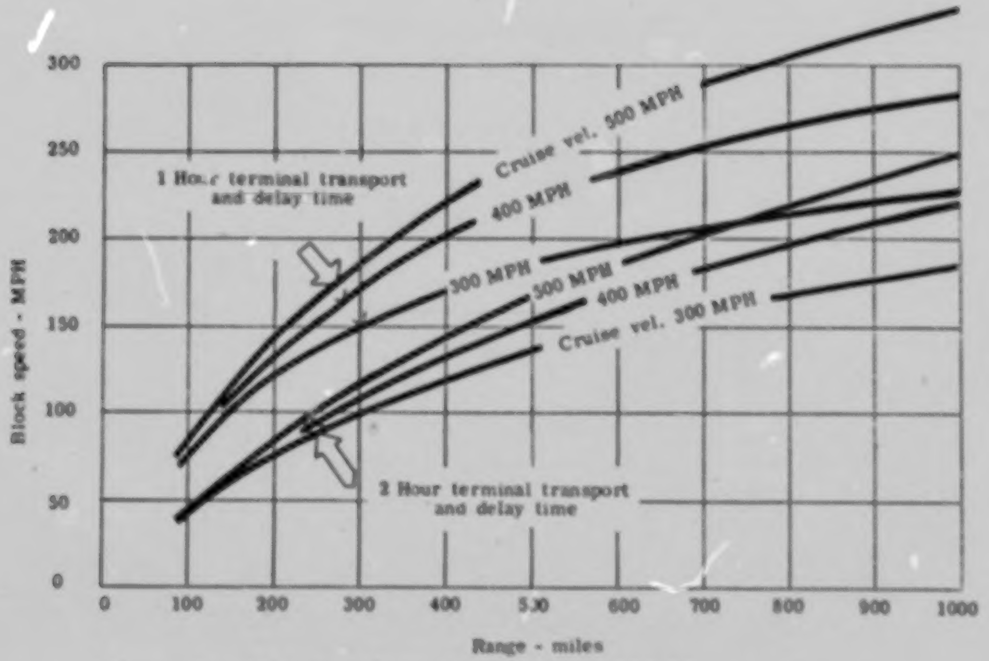


Figure 3.- Effect of terminal transport time and delay.

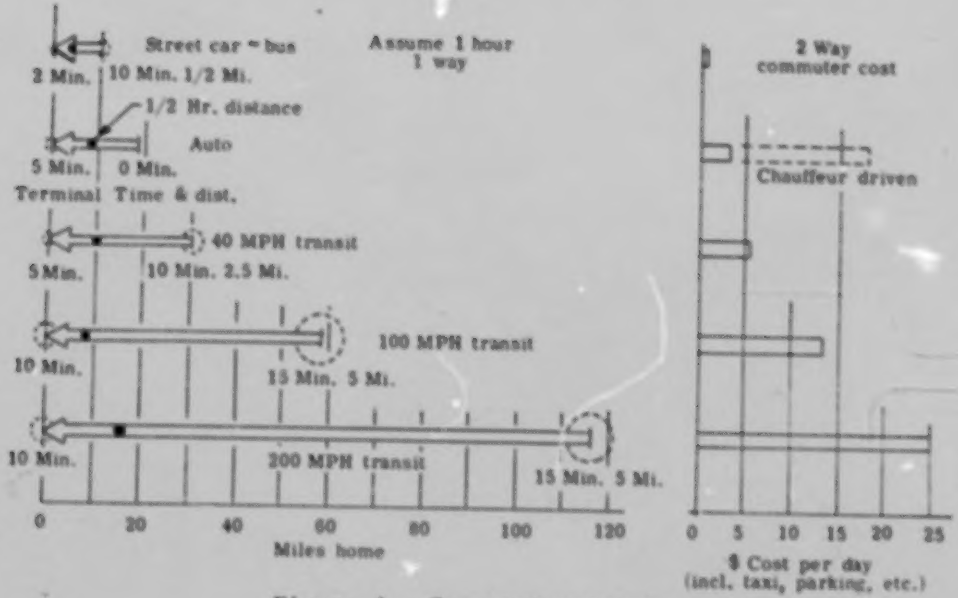
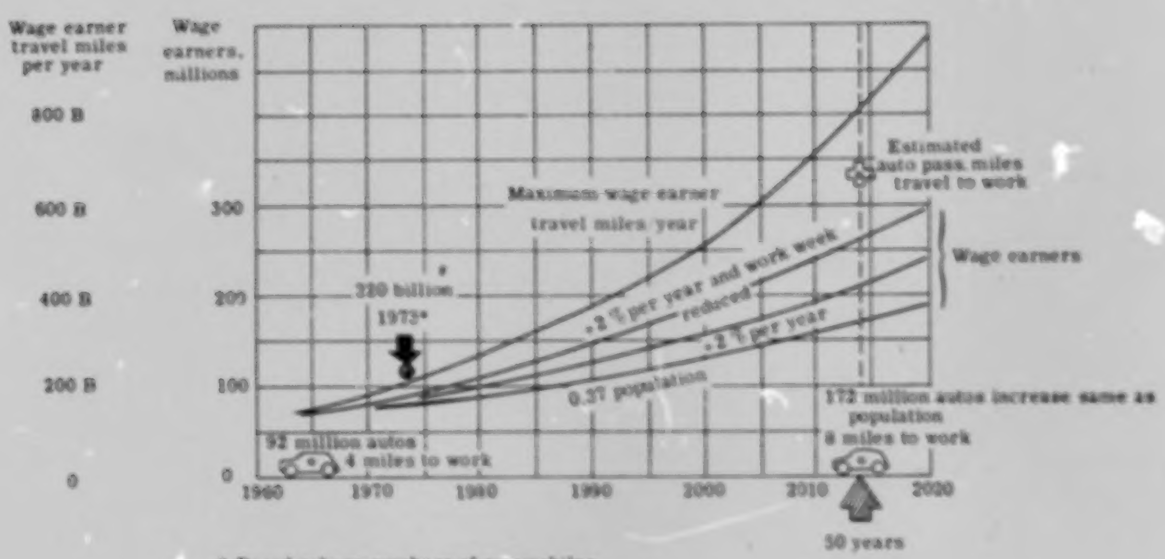


Figure 4.- Commuter patterns.



* Based only on numbers of automobiles

Figure 5.- Potential commuter travel.

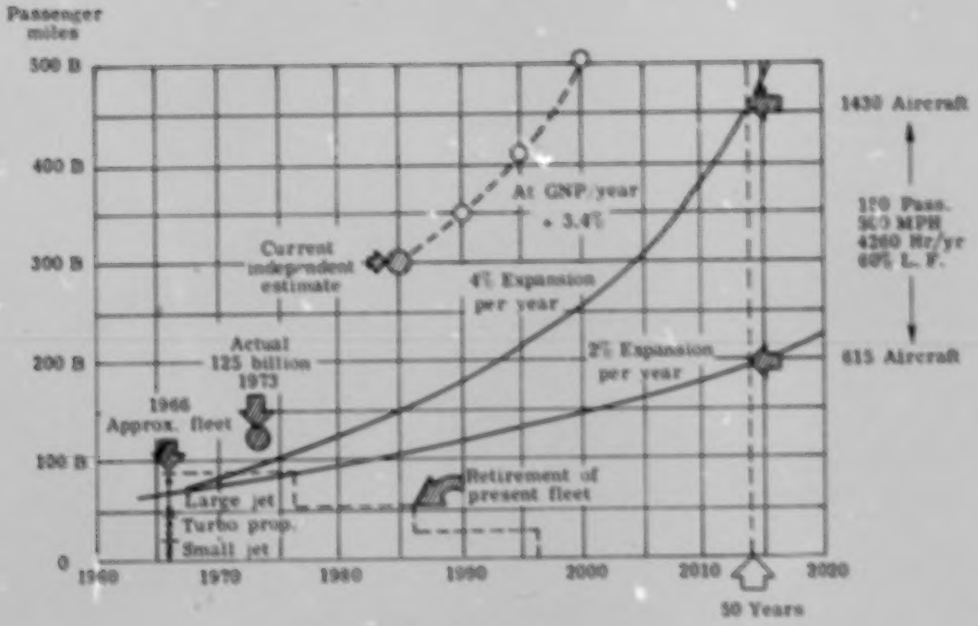


Figure 6.- Domestic travel.

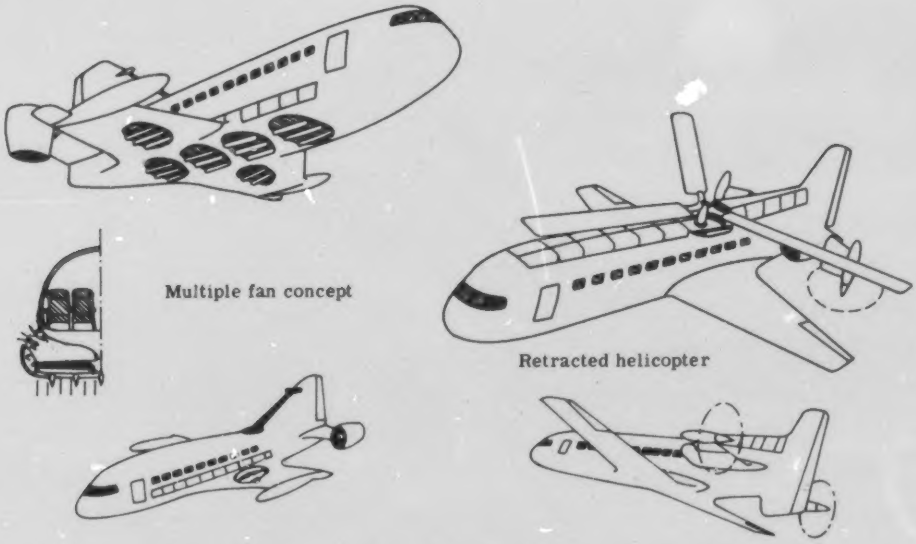
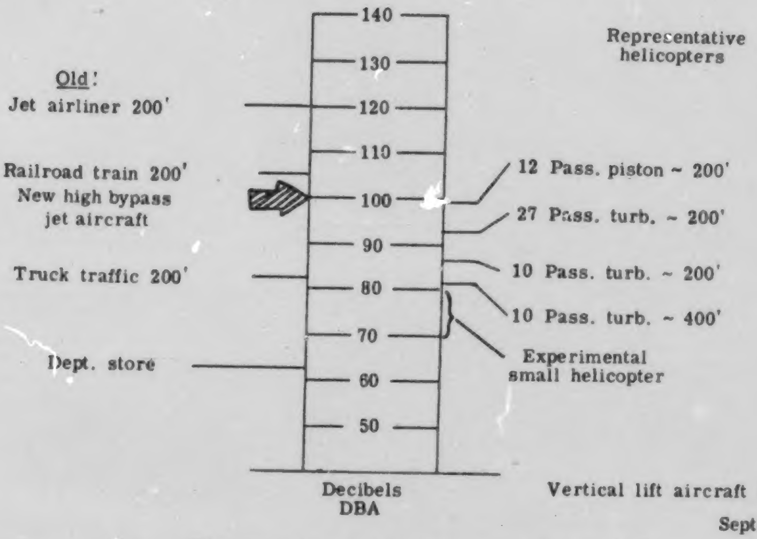

Multiple fan concept
Retracted helicopter

Figure 7.- Some current candidate commuter short-trunk aircraft.



Vertical lift aircraft council
Sept. 1963

Figure 8.- Noise comparisons.

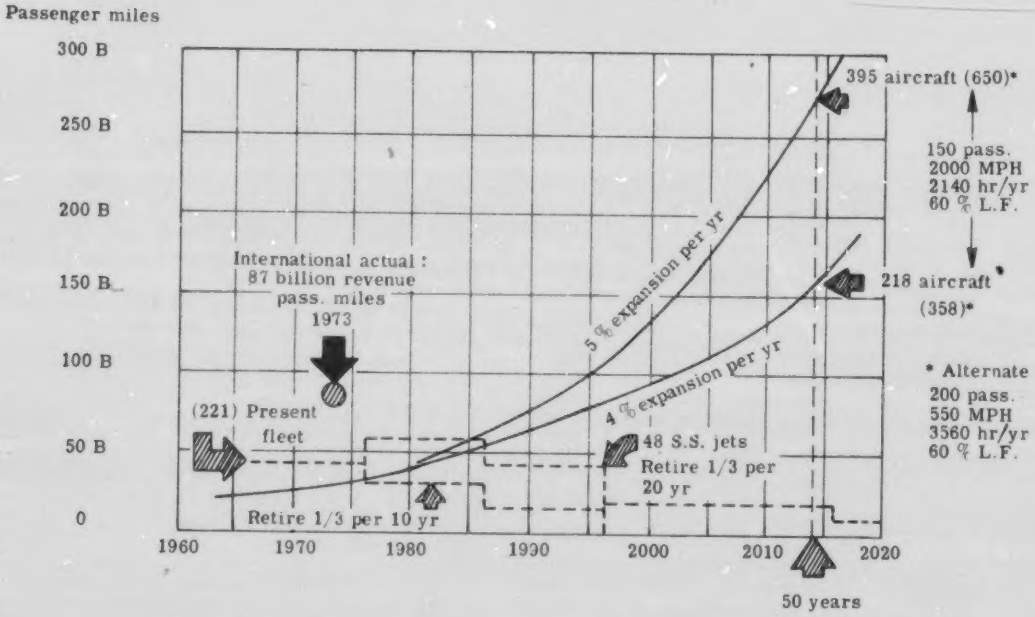


Figure 9.- International travel.

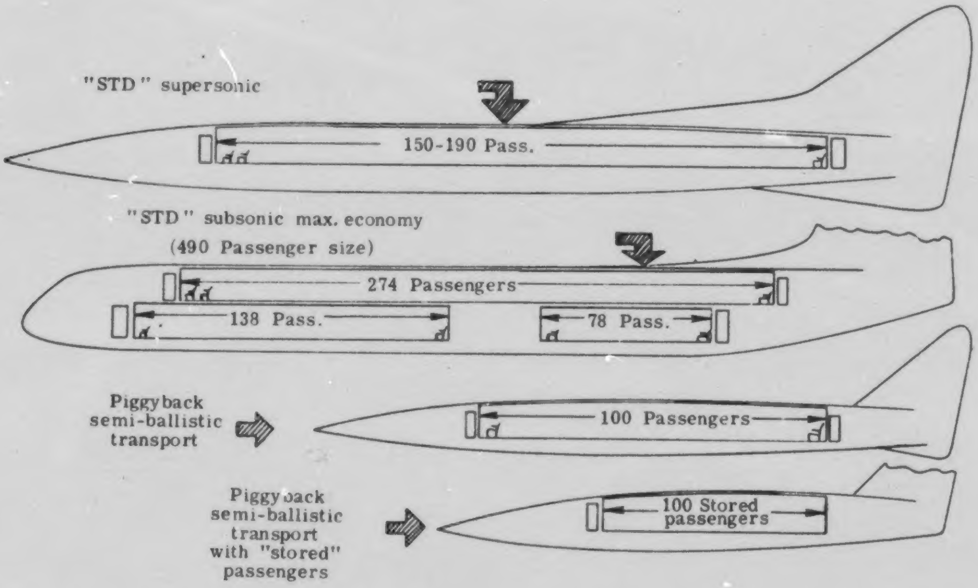

"STD" supersonic
150-190 Pass.
"STD" subsonic max. economy
(490 Passenger size)
274 Passengers
138 Pass.
78 Pass.
Piggyback
semi-ballistic
transport
100 Passengers
Piggyback
semi-ballistic
transport
with "stored"
passengers
100 Stored
passengers

Figure 10.- Alternate international transports.

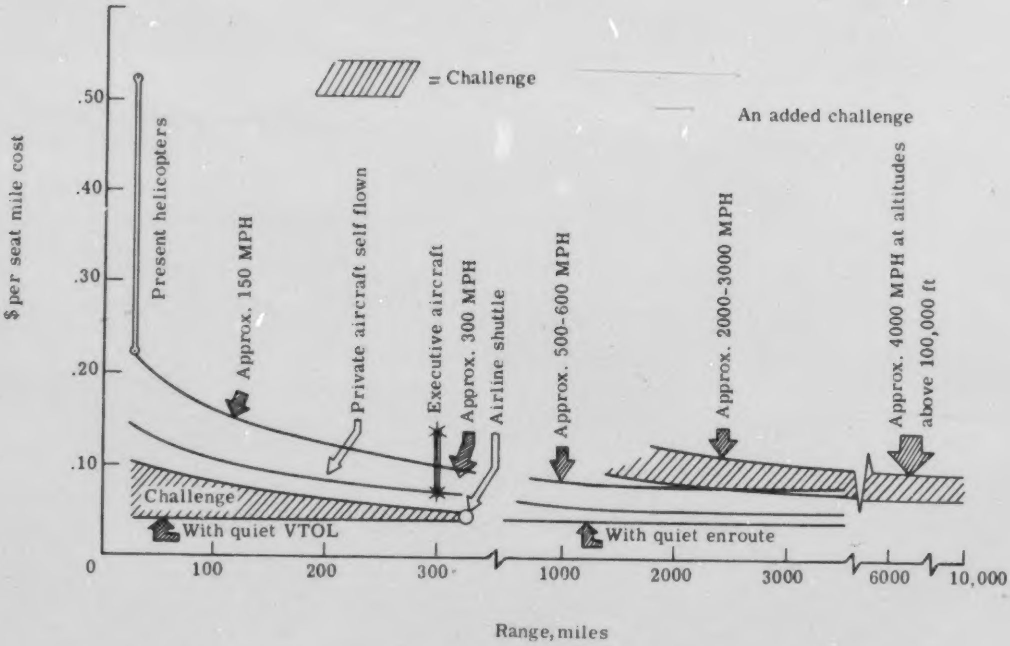


Figure 11.- Future challenge for air travel.

TRENDS IN AIRCRAFT NOISE CONTROL

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SUMMARY

Flight vehicles are characterized according to their manner of operation and type of propulsion system; and their associated sources of noise are identified. Available noise reduction technology as it related to engine cycle design and to powerplant component design is summarized. Such components as exhaust jets, fans, propellers, rotors, blown flaps, and reciprocating-engine exhausts are discussed, along with their noise reduction potentials.

Significant aircraft noise reductions are noted to have been accomplished by the application of available technology in support of noise certification rules. Further noise reductions to meet more stringent future noise regulations will require substantial additional technology developments. Improved analytical prediction methods, and well-controlled validation experiments supported by advanced-design aeroacoustic facilities, are required as a basis for an effective integrated systems approach to aircraft noise control.

INTRODUCTION

The purpose of this paper is to characterize the various types of flight vehicles, identify the important noise sources, provide brief descriptions of available noise control technology developments in each of several technical areas, and indicate future needs and research trends. Much of this paper and particularly the illustrations are derived from references 1 and 2.

External noise patterns are related closely to the operations of the aircraft, and those which are significant in community noise exposures are illustrated in figure 1. They occur largely at or near airports where landing approaches, ground operations, and takeoff-climbouts of commercial airplanes can adversely affect the noise in the airport community. The noise from low-altitude flights of general aviation aircraft or from localized helicopter flight operations can also be detrimental. Commercial air transport cruise operations usually occur at relatively high altitudes and, hence, exterior noise is not significant. On the other hand, interior noise may be a serious consideration for the comfort and safety of the occupants in all types of aircraft. Sonic-boom exposures which are recognized as a particular problem for supersonic and hypersonic aircraft in transition and cruise flight are not considered in this paper.

Figure 2 constitutes a broad outline of this paper. Some of the many factors that can affect noise are indicated in the schematic diagrams of the figure. One such factor is the type of aircraft; and depending on whether it is a propeller or rotor vehicle, a jet vehicle, or a powered-lift vehicle, its noise characteristics can vary widely. These variations arise because of the different types of operations involved and the associated powerplants which provide the needed operational capabilities. The overall aircraft configuration and its operating conditions determine the relative importance of such characteristic sources of noise as engine exhausts, rotating blades, and airflow-surface interactions. Another factor is the state of the art of noise control technology which is designed into the aircraft. For instance, the type of engine cycle and its component design; the type and amount of acoustic duct and surface treatment and shielding; the presence or absence of exhaust suppressors, mufflers, and high Mach number inlets; and the possible use of noise abatement operating procedures, can markedly influence the external noise.

With regard to the future, the development of new noise control technology and prediction methods, and the development of appropriate new noise regulations will be important factors, and may in turn influence new aircraft design.

TYPES OF AIRCRAFT AND THEIR NOISE SOURCES

The size, shape, and propulsion system of an aircraft are determined by the character of its mission, particularly the range. Different types of aircraft such as general aviation, VTOL, STOL, CTOL, and SST/HST have thus evolved to satisfy particular needs. Because of the inherent differences in airplane configuration and powerplant type, their flyover noise characteristics also differ as indicated in figure 3. Schematic illustrations of related spectral characteristics of the noise signatures of various types of vehicles are shown at the bottom of the figure. These data are generally representative of the noise produced during takeoffs, landing approaches, and ground operations of these aircraft. These are only qualitative representations and no attempt has been made to normalize them on an amplitude basis. These spectra consist of the superposition of broadband noise and discrete frequency components as illustrated by the shaded areas and heavy vertical lines, respectively, in the bottom sketches. It can be seen that the spectral characteristics of the noise are different from one type of aircraft to another. They range from essentially broadband noise for the SST/HST to combinations involving both high- and low-frequency discrete tones for CTOL and general aviation aircraft, respectively. A knowledge of the source of the noise and its physical characteristics are both important because they determine the requirements for noise control. Such widely differing noise characteristics as are indicated in figure 3, suggest the need for widely different approaches to noise control from one type of vehicle to another.

The main sources of noise for the characteristic types of aircraft under consideration in this paper are listed in figure 4. The sources of noise are conveniently categorized as either from the powerplant, which includes the engine and its components and, in some cases, the propulsor unit, or from the airframe. Powerplant noise is seen to arise from the rotating blades of either free rotors, propellers, or ducted fans; and from the exhausts of either reciprocating or gas turbine engines. Airframe noise, on the other hand, results from interactions of airflow over the entire external surfaces of the CTOL and SST/HST aircraft and, in the case of STOL aircraft, from the exhaust impingement on wing and flap surfaces.

EXTERIOR NOISE

Discussion is directed to the current state of the art of exterior noise control technology. Emphasis is placed on the main sources of noise identified in figure 4 and attempts are made to illustrate the manner in which noise emissions can be beneficially affected by changes in geometry or operating conditions of the noise-producing component or the aircraft itself, or by acoustic surface treatments. Material presented in this section has been summarized from references 1 to 13.

Noise Source Considerations

Reciprocating engines.- The sources of noise from reciprocating engines, which are in widespread use in general aviation vehicles and small helicopters, are the air intakes, the pulsing-flow exhausts, and the accessories. (See refs. 3 and 4). Of these, the exhaust noise is usually the major engine noise component and is the most difficult to control. The data of figure 5 illustrate the effectiveness of a conventional exhaust muffler of the type shown in the cutaway sketch in the upper left when applied to a reciprocating-engine powered helicopter for which engine noise was the dominant noise component. The photograph at the right in figure 5 is a closeup of the helicopter with a flight-certified exhaust muffler installed. The diagram at the bottom of the figure illustrates the helicopter noise spectra with and without the engine exhaust muffler installed. The muffler is seen to reduce substantially the intense engine exhaust peaks at the lower frequencies and to cause a general reduction of the broadband noise at the higher frequencies. Mufflers of this type can be very effective acoustically with minimal performance penalties.

Free rotors.- The general situation with regard to free rotor blade noise control is indicated in figure 6. The data are meant to be generally representative of main rotors and tail rotors of helicopters, VTOL tilt rotors, and conventional propellers, as suggested by the sketches at the top of the figure.

Shown in the lower left portion of the figure by the hatching are the relative perceived noise levels (PNL) as a function of tip speed for rotors which provide equal thrust. The main point of the figure is to suggest that tip speed is a dominant factor in the control of free rotor blade noise. Generally speaking, as tip speed is reduced, overall noise levels are reduced and there is a trend toward a reduction of the levels of the high frequency spectral components. At a given tip speed, such factors as aerodynamic loading and blade geometry can be significant, and their combined effects are represented by the vertical dimension of the hatched area. The relative importance of these other two factors is illustrated by the bargraph in the lower right of the figure. The suggestion is that the proper control of both the steady and the fluctuating aerodynamic loads on the blades can, thus, be very beneficial. The less effective, but nevertheless significant, geometry factor includes such items as blade thickness, surface roughness, number of blades, and airfoil shape. (See refs. 1 and 5).

Turbofan engines.- As shown schematically on the engine cross section of figure 7, noise generated by the fan and the compressor propagate forward out of the nacelle inlet. Fan noise also propagates rearward out of the fan duct. Noises generated by the combustor, turbine stages, and struts, frequently referred to as "core noise," propagate rearward out of the core engine exhaust. In addition, both of the jets from the fan nozzle and from the core nozzle mix violently with the slower moving ambient air and produce jet noise.

Figure 8 presents noise level data from a large number of jet engines plotted as a function of jet velocity, and normalized to a given thrust level and distance. (See ref. 6). At the top of the figure are shown sketches which illustrate the general types of jet engines associated with the various jet velocity regimes. For instance, at the right-hand side of the figure, the data relate to turbojet-type engines, whereas at the left side of the figure, the data are representative of high-bypass-ratio-type jet engines having coannular exhaust streams. It can be seen that the relative perceived noise levels decrease, generally, as jet velocity decreases.

Noise from the high-velocity jet engine is mainly from the jet mixing process and current methods of jet noise reduction involve the use of exhuast noise suppressors which break up the main jet and, in effect, change the manner in which it mixes with the ambient air. Such suppressors have produced substantial noise reductions at the higher jet velocities as indicated by the cross hatching in figure 8, but their effectiveness generally reduces as jet velocity reduces and as forward flight speed increases. Recent experimental suppressors have associated static thrust losses as low as 0.25 percent per PNdB of noise reduction (see refs. 1, 2, and 7) although mechanical and structural integrity problems remain substantial.

The noise levels at the lower velocities are higher than would be expected based on jet mixing noise only. This increase is due to internal or core noise mentioned above.

Each of the engine noises is characterized by a frequency spectrum. Several of these are superimposed in figure 9. These data represent the noise components from the NASA quiet engine A (unsuppressed) at approach power and 50° from the fan inlet centerline. In this case, it is seen that fan noise is dominant; however, if the fan noise was sufficiently reduced, jet noise would then dominate. There is thus an obvious layering which must be recognized in the methodology of reducing engine noise.

Powered-lift systems.- In the case of powered-lift aircraft, the interactions of the jet engine exhaust with the wing and flap surfaces can be significant noise sources. Some of these interaction noise sources are identified in figure 10 for three conceptual designs for powered-lift aircraft (from ref. 8). The noise may be due to the impingement of the flow on the surfaces or due to the edge effects as flow traverses the wing and flaps. The use of special flow devices and materials to vary the effective edge impedance have shown beneficial noise reduction results. (See ref. 9).

Airframes.- Some of the nonpropulsive noise sources are identified in figure 11. Noise produced by the interactions of flows with solid surfaces of the aircraft is becoming of increased significance as the technology improves for reducing the noise from the aircraft powerplants. Noise is produced by aerodynamic boundary layers, by the flow past projections such as landing gear struts, by flows in cavities such as wheel wells, and by turbulent flows and wakes. (See ref. 10). For aircraft in flight, many of these sources act simultaneously to produce the overall nonpropulsive noise signature.

Some example data which illustrate the relative levels of nonpropulsive noise for representative commercial airplanes are given in figure 12. The approach noise levels for a number of operational airplanes at normal approach power conditions are shown as the circle data points. The hatched region at the bottom of the figure represents the estimated ranges of levels, based on flight data, for the nonpropulsive noise associated with those airplanes (from ref. 1). The data points are above the hatched region, thus, indicating that the propulsive noise dominates for current aircraft. For proposed future aircraft having quieter powerplants, the nonpropulsive or airframe noise may be a significant component, and appropriate methods of control will be needed.

Acoustic Treatments

A very effective and necessary means of reducing noise after it is generated in the engine nacelle and before it propagates into the atmosphere is the application of acoustic treatment to the walls of the engine ducts. Figure 13 indicates the areas in which sound-absorbing materials (or acoustic treatment) will most likely be used in future engine installations. This treatment consists of backup cavity structures and porous or perforated face plates. Some possible configurations of surface treatments are shown schematically at the bottom of the figure. Single element and multielement configurations have been used as a means for meeting noise certification rules. (See ref. 2, 7, and 12). Segmented liners may have added noise reduction potential; however, there are no readily available methods for optimizing their design.

One of the future needs is, thus, proven methodology for the design of optimum acoustical treatments for a particular duct environment. This leads to the need for several items of technology including the development of materials that are stable and predictable acoustically; and that provide broadband noise alleviations over a wide range of flow Mach numbers and ambient temperatures. In addition, a reliable optimization method of iterative design is needed to improve the efficiency of duct treatment applications.

High Mach Number Inlets

There is a significant noise reduction potential to be realized by the use of high-throat Mach number inlets for turbofan engines. This is based on the principle that waves propagating against the flow are retarded by high-flow Mach numbers and are completely blocked in a region of aerodynamically choked flow. The data of figure 14 illustrate the noise reductions obtained in inlet radiated noise from a large number of studies as a function of throat Mach number. These results indicated that substantial noise reductions may be obtained at the higher Mach numbers. The extreme case of choked flow provides the largest noise reductions; however, much work is needed to reduce the complexity and weight of the variable geometry hardware needed to keep the throat velocity choked for both approach and takeoff engine speeds. There is also substantial potential for noise reductions at Mach numbers lower than sonic where variable geometry devices are not required. This has led to the concept of a high Mach number inlet with acoustic treatment so that part of the noise reduction comes from the liner and part from the flow effects. This is now referred to as a hybrid inlet and considerable research is needed to optimize its design for performance and noise reduction.

Noise Shielding of Aircraft Structure

One way in which the ground noise exposure can be lessened is by the use of shielding by the wings, empennage, and fuselage to interrupt the propagation of noise from the engines to the ground. (See ref. 13). Some configurations for accomplishing shielding are shown in figure 15. At the top left is shown a current configuration in which the inlet noise radiation pattern is interrupted by the wing, the net effect being a lower inlet noise level with a shorter duration. The lower left diagram shows an engine-over-wing configuration proposed for shielding from jet noise radiation. The right-hand sketch represents a possible high-speed airplane with over-the-wing engines, configured to provide substantial noise shielding and at the same time enhance the performance of the aircraft. Configurations with optimized shielding are under consideration for the future.

Noise Abatement Operations

The ground noise exposures of any particular airplane are closely related to the manner in which it is operated. Thus, the noise in airport communities can vary considerably depending on the particular climbout or landing approach profiles that are in use. In figure 16, an illustration of the beneficial effects of noise reduction procedures in landing approach are shown (from ref. 2). The solid contour lines of 90 and 95 EPNdB are the results of the standard landing approach procedures for a conventional three-engine jet airliner. On the other hand, the dashed contour lines in each case are associated with a proposed two-segment approach such as indicated schematically in the sketch at the top of the figure. It can be seen that the two-segment procedure results in a marked shortening of the ground exposure patterns and an associated reduction of the enclosed areas. The reduced noise at the greater distances from the airport results from the increased altitude of the airplane and the reduced-power requirements of the steeper approach path. Safe and routine usage of other than conventional straight-in approaches will require further development of appropriate ground and onboard equipment.

INTERIOR NOISE

Figure 17 contains some summary data relating to the ranges of noise levels inside the passenger and crew compartments of three different types of aircraft. The lower shaded region represents the ranges of measurements made in a number of CTOL aircraft. Although there are no generally agreed on criteria for interior noise exposures, those of the figure have given rise to very few complaints from the standpoint of passenger comfort. On the other hand, the measured general aviation noise levels represented by the hatched region have generally higher levels, particularly in the lower frequency bands, and it is judged that this type of noise in some cases interferes with communication and in extreme cases may be injurious to hearing. Noises from the propulsion systems of all types of propeller-driven aircraft have relatively strong low frequency components and the fuselage wall noise reduction is relatively small in this frequency range. The solid curve which has been estimated for an upper-surface blowing STOL configuration having conventional skin stringer construction indicates still higher levels in the low frequencies. Such high levels result from the fact that the engines are close to the fuselage and the exhaust flows adhere to, and closely couple with, the airplane structure. Although established criteria are also lacking for STOL interior noise comfort, the estimated levels are probably unacceptable. Both comfort criteria, and acceptable means of acoustic insulation are needed as a basis for interior noise control.

FUTURE TECHNOLOGY NEEDS AND RESEARCH TRENDS

The discussions up to this point have identified some of the individual sources of noise on various types of aircraft; have evaluated the noise variations as a function of geometric and operational parameters; and have indicated the noise reduction potential wherever possible. As a result of these several studies, it is possible to define trends in noise reduction and goals for future aircraft noise levels.

Goals

An indication of the trend in takeoff-climbout and landing approach noise levels for conventional commercial aircraft as a function of time is given in the data of figure 18. The noise levels specified in FAR part 36 (ref. 14) are used as a reference, and the differences between those and actual levels are plotted on the vertical scale. Data are shown for landing approach and side-line by the squares and diamonds, respectively, and for takeoff-climbout by the circles. Prior to the publication of FAR part 36, it is seen that the noise levels are generally higher than those of the regulations. New designs certified after the regulations came into effect had markedly lower noise levels than the older aircraft. The substantial accomplishments indicated as a function of time were due at least in part to the existence of regulations and the forced application of available technology. It has been proposed (ref. 15) that the noise certification levels for CTOL aircraft be reduced, eventually, an additional 10 to 20 EPNdB, as indicated by the shaded area at the bottom of the figure. Such future noise reductions are likely to come mainly as a result of appropriate regulations. The implementation of new regulations in turn can be achieved only with the development and application of a substantial amount of new technology.

The proposed federal noise standards for propeller-driven small airplanes as a function of gross weight (ref. 16) are represented by the solid curve in figure 19. Also shown in the figure are noise level data for a large number of currently operating general aviation propeller-driven vehicles, represented by the open symbols (ref. 17), and for a few experimental propeller-driven aircraft by the solid symbols (ref. 1). The above data are for the conditions of maximum continuous power in level flight at an altitude of 305 m. It can be seen that the data represented by the open symbols scatter about the curve. Some of the open data points and all the solid data points are lower than the proposed requirements. Although considerable noise control technology is available as a basis for meeting the proposed requirements, confirmed methods of optimizing the designs are not readily available.

Prediction Methods

One of the greatest needs in the development of quieter aircraft designs is the ability to predict reliably the noise from an aircraft in flight based on a knowledge of its geometry and operating conditions. (See ref. 1). One commonly used method, as suggested in the top of figure 20, is to measure the noise during flyover for known flight conditions and to use such measurements as a basis for predicting the ground noise contours for the operational envelope of the airplane. This is a useful method except for the fact that the data are available only after the aircraft is flight operational.

Other approaches to noise prediction are in various stages of development. (See ref. 18). These are illustrated by the block diagrams at the bottom of figure 20. One approach is to use airplane noise data from the ground static operating conditions, and then adjust for forward flight and atmospheric propagation effects. Another approach is to use engine static-test-stand noise data and, in addition, to incorporate installation effects. The third approach is mainly analytical and based on a thorough understanding of the noise-producing phenomena and their interactions inside the engine as well as the installation, forward flight, and atmospheric effects. The satisfactory implementation of these prediction methods requires substantial additional technology developments especially for the analytical approach.

Aeroacoustic Facilities

The strong demands for improved noise reduction technology as a basis for meeting anticipated new noise certification and operational regulations suggest that more rigorous analytical methods of noise prediction will be needed in the future, as mentioned above. Hand in hand with the need for analytical methods is the need for well-controlled experiments to provide validation of analytical concepts and to establish the useful ranges of application of analytical methods. Such a need is not completely fulfilled by such well-established acoustical facilities as anechoic and reverberation rooms, impedance tubes, etc., nor are conventional wind-tunnel facilities wholly adequate. (See ref. 19). There is a rigid requirement for the ability to simulate, under close control, forward motion effects in a free field acoustic environment. Figure 21 contains sketches which illustrate the types of testing facilities needed, short of full-scale evaluation under flight conditions.

There is a need for providing a realistic aerodynamic flow and acoustic field environment for acoustic materials that are proposed for operation in flowing ducts. (See fig. 21(a)). The behavior of the propagating sound field will be significantly affected by the mean velocity gradients in the duct and the acoustical behavior of the treated surfaces will be affected by the aerodynamic boundary-layer flow interactions with the microscopic flow patterns in the materials.

Specially designed acoustic wind-tunnel type facilities, either closed test section or open-throat test-section types, will probably be the workhorse facilities of the future for flow-induced noise generation and control studies. (See fig. 21(b)).

Needs may also arise for special facilities in which the model being tested will move through the air in order to assist in the interpretation of fixed model-moving stream data and to provide more realistic representations of time-varying effects such as Doppler shifts. (See fig. 21(c)).

Economics

The results of the NASA quiet engine project have demonstrated that future engines can be made quieter than those of the current wide-body jets. It is clear, however, that further noise reductions may result in increased airplane operating cost, unless proper advantage is taken of the advanced technology developments referred to previously in this paper. An ultimate trade-off may take the form illustrated in figure 22, in which reduced noise exposure for the ground population (number of people exposed to 90 EPNdB or greater per takeoff for a New York to Los Angeles flight) is balanced against an estimated increased ticket price. The solid line represents the cost of noise reduction for application of known technology. (See ref. 20 and 21). The hatched region is estimated for advanced technology developments, and it is seen that either a given noise exposure can be achieved at a lower cost or, conversely, for a given cost, more noise reduction can be achieved.

CONCLUDING REMARKS

The trends established for aircraft noise control lead to obvious needs for new technology. The progress to date has occurred as a result of fragmentary efforts directed at such elements of the problem as component noise source reduction, the use of noise control operational procedures, noise certification, evaluation criteria, and land use planning. The realization of future goals for aircraft noise reduction will require an integrated systems approach wherein the individual elements of the system will be weighted properly and will function in a compatible way. This suggests the need for valid analytical methods of predicting noise generation and its propagation through ducts and the atmosphere. In support of the systems approach, several technology items are required: improved component noise reduction, improved analytical prediction methods, specialized research and development facilities, and improved evaluation and acceptance criteria. Only by a concerted effort to plan for aircraft noise control by a systems approach will the desired results be obtained at an acceptable cost and in a useful time period.

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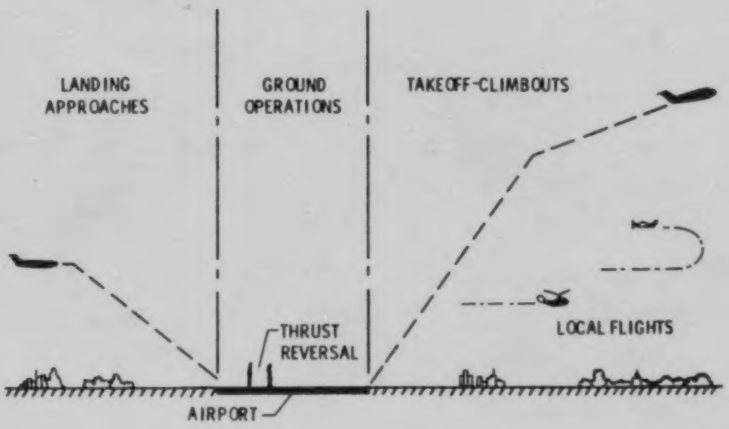

LANDING APPROACHES
GROUND OPERATIONS
TAKEOFF-CLIMBOUTS
THRUST REVERSAL
LOCAL FLIGHTS
AIRPORT

Figure 1.- Aircraft operations significant for community noise exposures (see ref. 1).

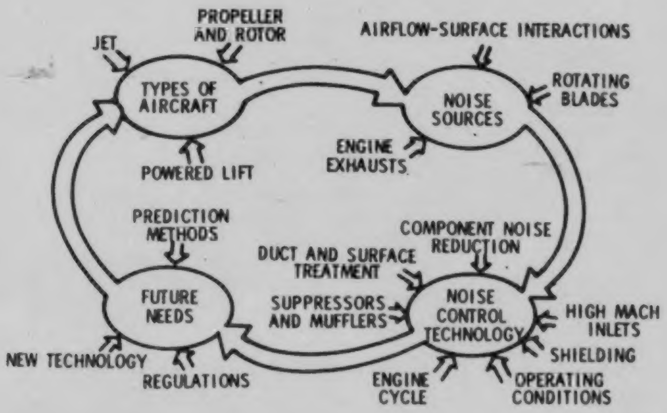

JET
PROPELLER AND ROTOR
AIRFLOW-SURFACE INTERACTIONS
TYPES OF AIRCRAFT
NOISE SOURCES
ROTATING BLADES
POWERED LIFT
ENGINE EXHAUSTS
PREDICTION METHODS
COMPONENT NOISE REDUCTION
DUCT AND SURFACE TREATMENT
FUTURE NEEDS
SUPPRESSORS AND MUFFLERS
NOISE CONTROL TECHNOLOGY
HIGH MACH INLETS
SHIELDING
NEW TECHNOLOGY
REGULATIONS
ENGINE CYCLE
OPERATING CONDITIONS

Figure 2.- Factors in aircraft noise control (see ref. 1).

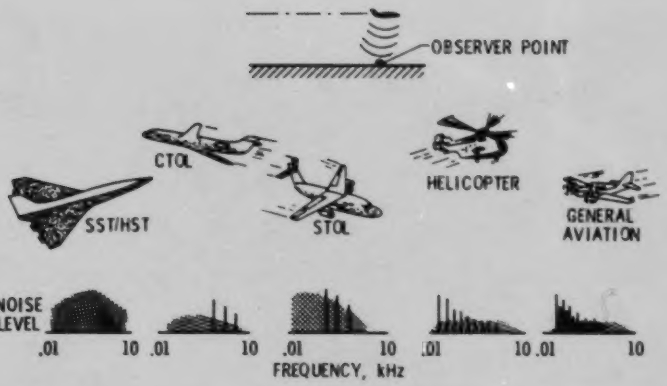

OBSERVER POINT
CTOL
SST/HST
STOL
HELICOPTER
GENERAL AVIATION
NOISE LEVEL
.01
10
.01
10
.01
10
.01
10
.01
10
FREQUENCY, kHz

Figure 3.- Characteristic flyover noise spectra for several different types of aircraft (from ref. 1).

TYPES OF AIRCRAFT	TYPES OF NOISE SOURCES	
	POWERPLANT	AIRFRAME
GENERAL AVIATION	PROPELLER BLADES RECIP. ENGINE EXHAUST	—
HELICOPTER	ROTOR BLADES RECIP. ENGINE EXHAUST	—
STOL	FAN BLADES JET ENGINE EXHAUST	JET/SURFACE INTERACTIONS
CTOL	FAN BLADES JET ENGINE EXHAUST	AIRFLOW/SURFACE INTERACTIONS
SST/HST	JET ENGINE EXHAUST	AIRFLOW/SURFACE INTERACTIONS

Figure 4.- Significant sources of noise for various types of aircraft (from ref. 1).

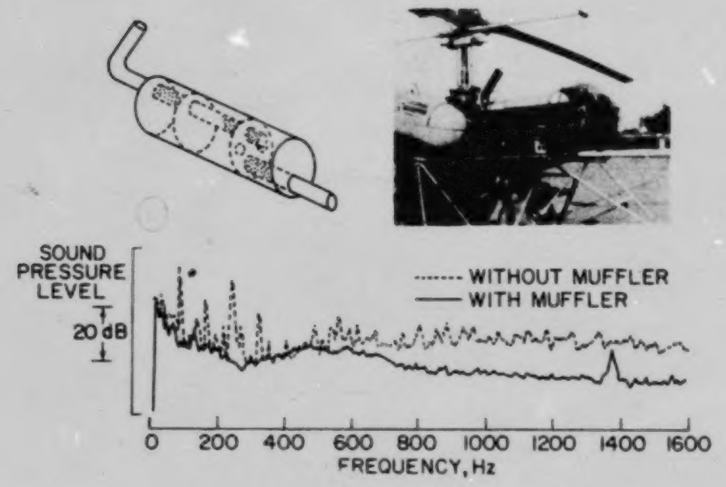


Figure 5.- Reciprocating-engine exhaust noise control (from ref. 1).

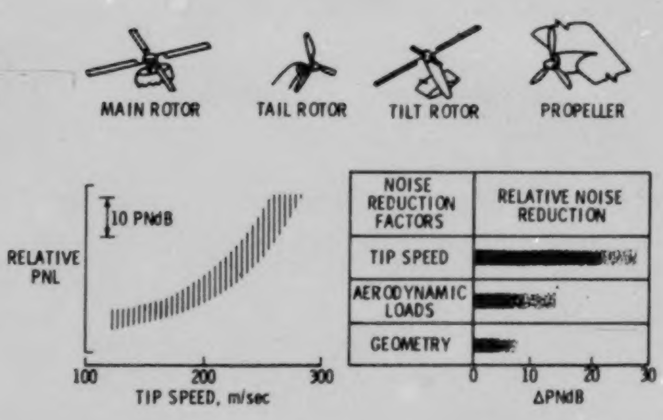


Figure 6.- Factors in the reduction of noise from free rotor blades (from ref. 1).

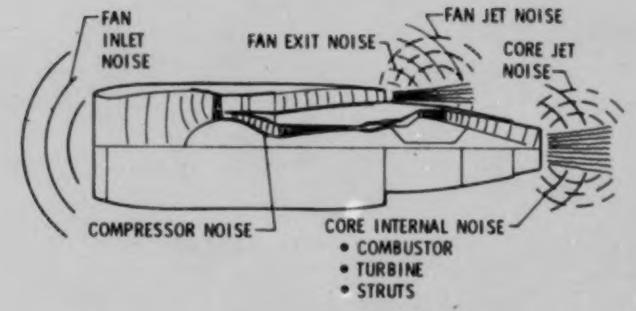

FAN INLET NOISE
FAN EXIT NOISE
FAN JET NOISE
CORE JET NOISE
COMPRESSOR NOISE
CORE INTERNAL NOISE
• COMBUSTOR
• TURBINE
• STRUTS

Figure 7.- Turbofan-engine noise sources.

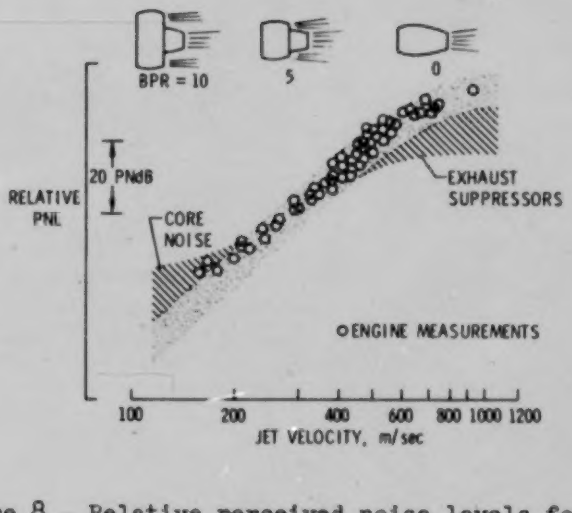


Figure 8.- Relative perceived noise levels for a number of jet engines as a function of jet velocity and normalized to constant values of thrust and distance (see ref. 1).

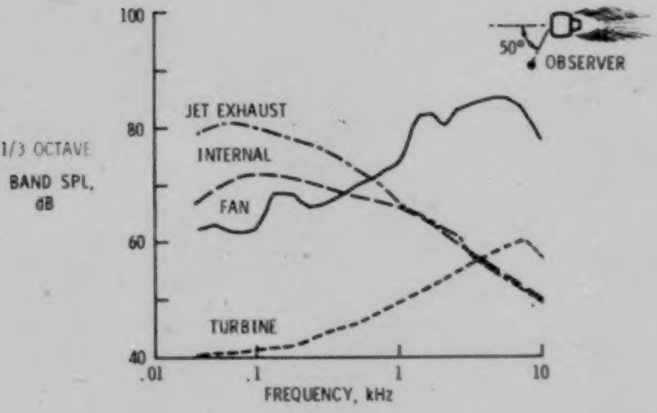
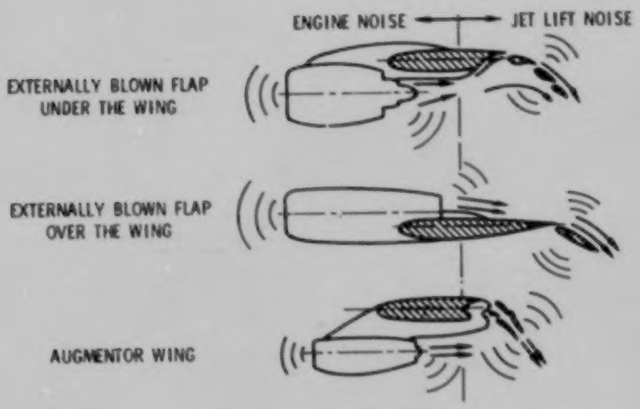


Figure 9.- Noise spectra associated with various components of NASA quiet engine A at approach power and at an angle of 50° from the thrust axis in front (from ref. 7).



ENGINE NOISE
JET LIFT NOISE
EXTERNALLY BLOWN FLAP UNDER THE WING
EXTERNALLY BLOWN FLAP OVER THE WING
AUGMENTOR WING

Figure 10.- Sources of noise from various types of powered-lift devices (from ref. 8).

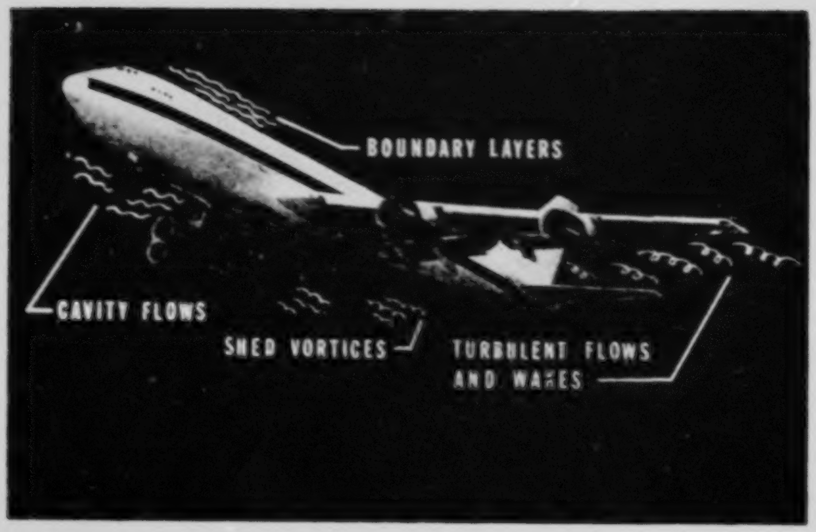

BOUNDARY LAYERS
CAVITY FLOWS
SHED VORTICES
TURBULENT FLOWS AND WAKES

Figure 11.- Sources of airplane nonpropulsive noise (see ref. 10).

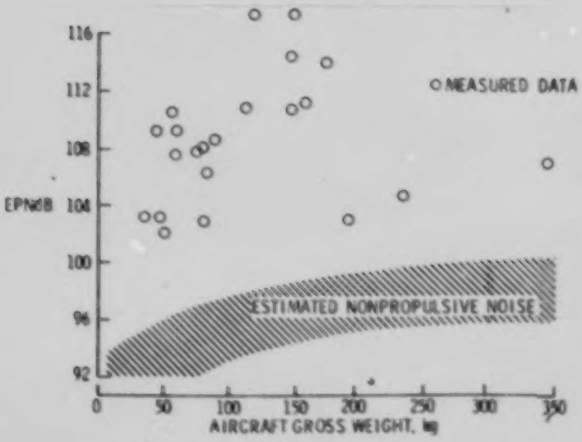


Figure 12.- Effective perceived noise levels for a number of current airplanes in the landing condition at an altitude of 122 m (from ref. 1).

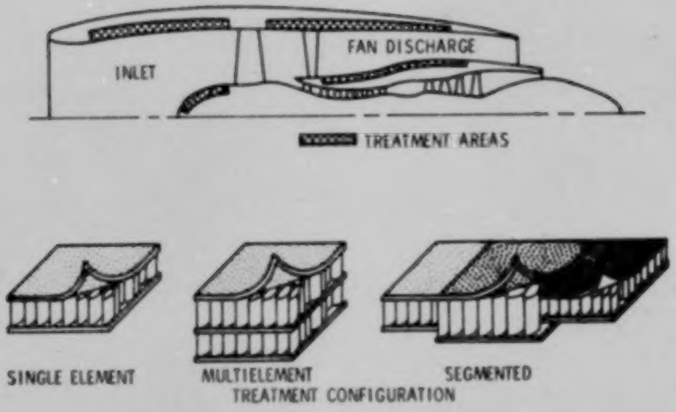

INLET
FAN DISCHARGE
TREATMENT AREAS
SINGLE ELEMENT
MULTIELEMENT
SEGMENTED
TREATMENT CONFIGURATION

Figure 13.- Acoustic treatment configurations for the nacelles of jet engines (from ref. 1).

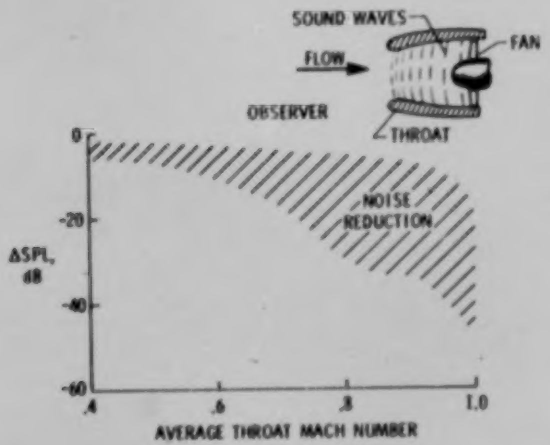


Figure 14.- Effects of throat Mach number on inlet noise radiation.

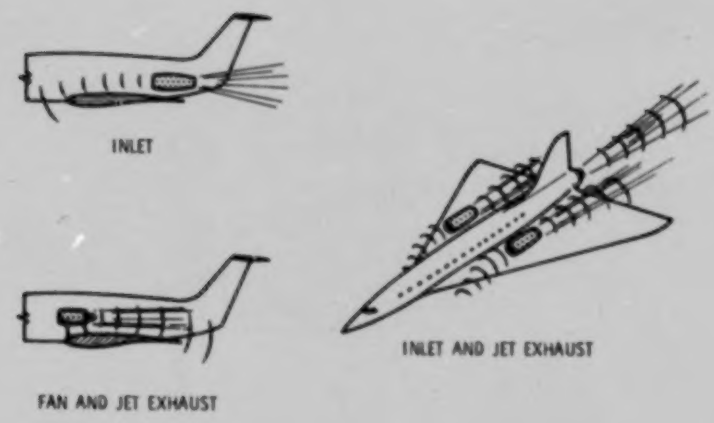

INLET
FAN AND JET EXHAUST
INLET AND JET EXHAUST

Figure 15.- Some aircraft configurations for engine noise shielding (see ref. 13).

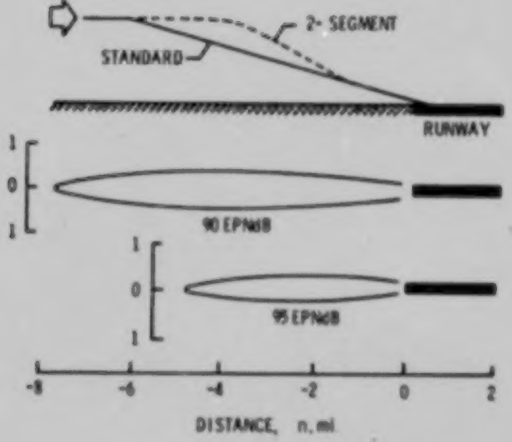


Figure 16.- Landing approach noise contours for three-engine commercial airplane (see ref. 2).

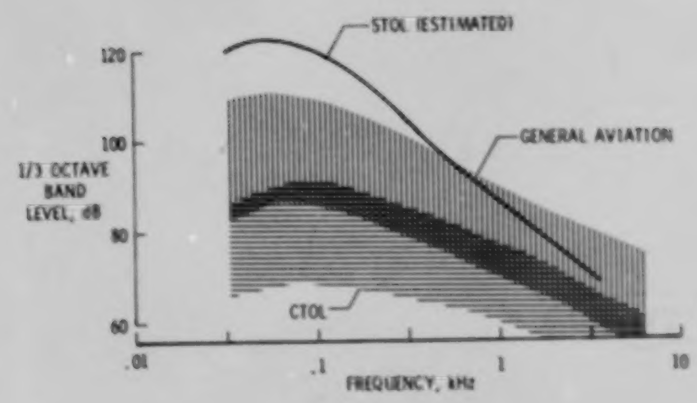


Figure 17.- Interior noise levels at cruise conditions for several types of aircraft.

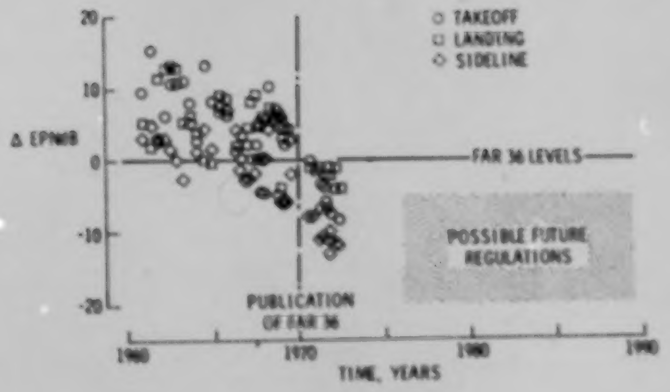


Figure 18.- Noise certification considerations for conventional takeoff and landing aircraft (from ref. 1).

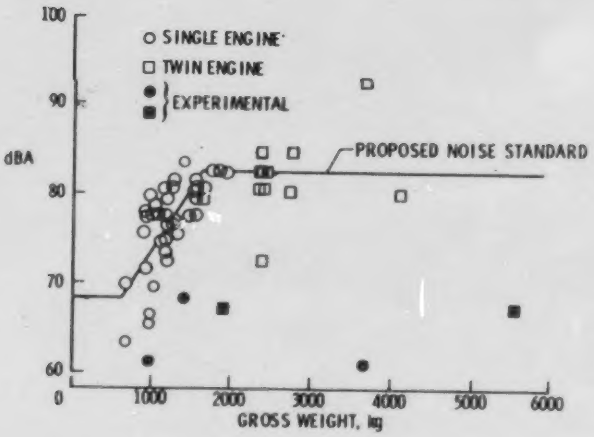


Figure 19.- "A-scale" noise levels as a function of gross weight for several propeller-driven light aircraft in level flyovers at an altitude of 305 m (see refs. 16 and 17).

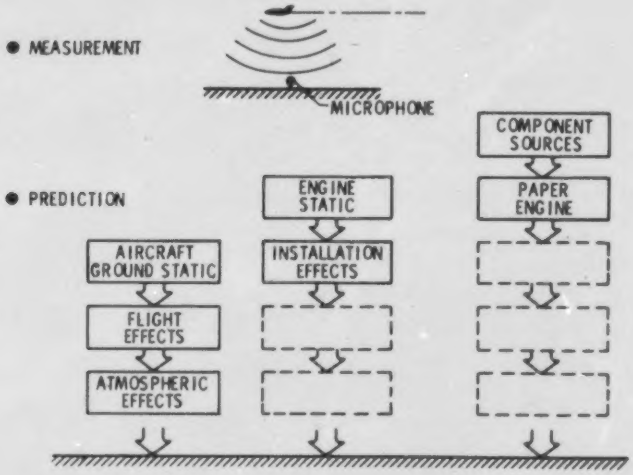

MEASUREMENT
MICROPHONE
PREDICTION
AIRCRAFT GROUND STATIC
FLIGHT EFFECTS
ATMOSPHERIC EFFECTS
ENGINE STATIC
INSTALLATION EFFECTS
COMPONENT SOURCES
PAPER ENGINE

Figure 20.- Methods of determining ground noise exposures from aircraft flyovers (from ref. 1).

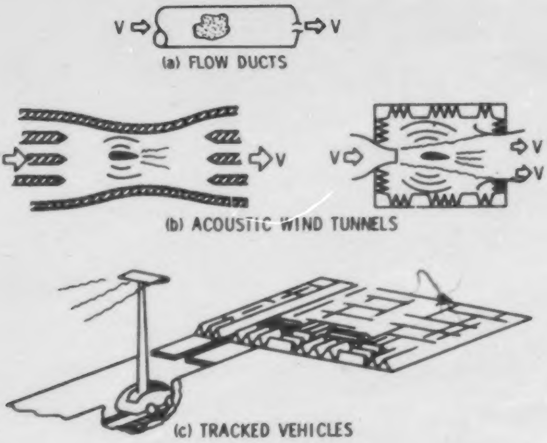

V
V
(a) FLOW DUCTS
V
V
V
V
V
(b) ACOUSTIC WIND TUNNELS
(c) TRACKED VEHICLES

Figure 21.- Schematic illustrations of various types of facilities proposed for future aeroacoustics research (from ref. 1).

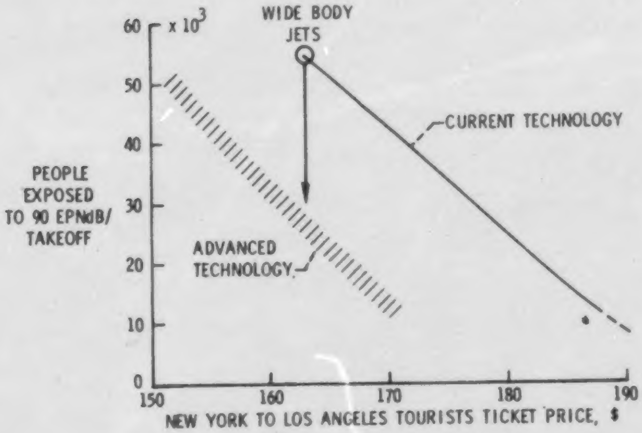


Figure 22.- Community noise relief versus cost to the traveler (based on data from ref. 21).

ASSESSING AND CONTROLLING THE EFFECT OF AIRCRAFT ON THE ENVIRONMENT - POLLUTION

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NASA Ames Research Center
and J. S. Grobman
NASA Lewis Research Center

INTRODUCTION

The problems posed by aircraft pollutants are political and technical, and the two are not easily decoupled. By political, we include public reaction to environmental effects, real or imagined. Although we will not dwell on the political problem, it is important to remember that technical assessments or solutions must be acceptable to the public. This is a problem which is not easily solved by scientists and engineers; but finding a political solution is critical for the progress of the very technology needed to assess and control aircraft pollution and this poses an important and interesting challenge to people who aspire to work in this field.

The technical aspects of the problem can be identified. It is necessary first to know what and how bad are the suspected pollution effects, then to search for ways to control the emission of pollutants, finally tradeoffs and implementation strategy need to be considered and this leads back to politics. At this time, progress is being made on assessment and methods of control; we do not yet know enough to consider tradeoffs.

KINDS OF POLLUTION PROBLEMS

The most obvious problem to most of us is the airport pollution problem, because we can smell the fuel and see the smoky exhausts. This is a local problem and can be mitigated by procedural techniques such as minimizing taxi time, locating airports in adjacent air basins, etc., as well as by improving aircraft engines. The local airport problem has not been thoroughly assessed, but to the general public it appears to be more of a nuisance than a public health problem. Although local pollution should not be dismissed lightly, it has not been considered to be serious enough to impede progress in the development of subsonic aircraft technology.

On the other hand, the suspicion that supersonic aircraft might cause global problems has seriously impeded progress in the development of technology for the next generation of air transportation. The elements of the supersonic aircraft pollution problem are the following.

1. Supersonic aircraft fly in the stratosphere.

2. The stratosphere is a relatively stable region of the atmosphere with very little vertical mixing; this is due to the positive temperature gradient illustrated in figure 1(a).

3. The stratosphere is rich in ozone (figure 1(b)) and therefore is the region in which the short wave length ultraviolet radiation is absorbed; it is that absorption of radiation that causes the positive temperature gradient and subsequent stability and, in addition, screens the earth's surface from harmful radiation.

4. Any pollutants left by supersonic aircraft in the stratosphere will remain for a relatively long time; and if they react to alter the ozone equilibrium, they can cause changes in ultraviolet absorption which in turn may cause public health problems and long term climatic change. The word may in the last sentence must be emphasized; the assessment of those suspected hazards is far from complete.

SOLUTIONS

Two solutions to the stratospheric pollution problem are obvious. The first is to develop reliable means for assessing the pollution effects and for monitoring them. The second is to develop cleaner engines. Assessments should provide information on how much traffic can be accommodated without serious degradation. As better engines become available, the traffic can be increased in proportion to the reduction achieved in pollutant emission. Monitoring systems will provide an important check on calculations and insure that supersonic traffic does not seriously deplete ozone.

Assessment

Assessment is mainly a mathematical modeling activity, but it requires a reliable data base of observations and laboratory measurements. Models are basically ensembles of continuity equations describing the production and loss of atmospheric species within a specified unit volume. Production and loss includes both chemical and mass transport terms. Each species must be accounted for and atoms must be conserved. The equations are then solved as functions of time and space, yielding distributions of the species being modeled. When models of the natural stratosphere are developed, we can modify them to simulate the introduction of pollutants. However, we have to be confident that the models are in fact, realistic; observational results indicate that the models are developing satisfactorily but do not yet simulate nature.

The principal problem is that global circulation patterns must be generated by a successful model and that the chemical activity of the pollutants must be included so that the mutual influences of chemistry and circulation can be accounted for. This requires a three-dimensional interactive model that is reasonably economical of computer time. We are working our way up the hierarchy of models. Several one-dimensional models (vertical profiles) are available that include the full chemistry (over 40 species and over 100 reactions) and parameterized vertical transport; a sample of 1-D results is shown in figure 2. For these models to be realistic would require that atmospheric constituents be uniformly distributed around the globe; we know this is not the case by such observational evidence as the global distribution of ozone. Two-dimensional models (figure 3) provide vertical and horizontal distribution along a meridian; several of these are now available and are being used. The two-dimensional model uses parameterized meridional transport in addition to vertical transport but necessitates a truncated chemical reaction set. Thus one of the real values of one-dimensional models is to be able to study the full range of chemistry and to decide which reactions are sufficiently important to include in the two- and three-dimensional models.

Work on three-dimensional models are underway. It is believed that within 2-3 years useful global interactive models with adequate chemistry will be available, then the task of assessment will begin in earnest. Such global models require state-of-the-art computing facilities such as ILLIAC IV or STAR which will probably only be available at a few government laboratories.

Assessments with current models indicate that nitric oxides emitted by 500 SST flights per day will cause a 5 - 15% depletion of stratospheric ozone, depending upon various assumptions made. Although one can argue with assumptions and modeling details, it appears that supersonic air transport traffic is a potential problem and that there is good cause for concern.

Along with the models, of course, we must have measurements of key stratospheric constituents. Again, we must push the state of knowledge because little is known about such important species as NO, NO_2, and HNO_3; OH, O, and HCl have never been measured. The problem can be appreciated by studying the profiles generated by one-dimensional models (figure 2); the concentrations of the important constituents are less than 1 ppb and, in some cases, several orders of magnitude less.

There are now several stratospheric measurements activities. The Nimbus satellites have been measuring ozone globally for several years and this complements frequent balloon soundings and occasional rocket soundings. Balloon and lidar probes observe stratospheric aerosol layers but the measurements are sparse. The DOT has been surveying the stratosphere for a number of constituents (including oxides of nitrogen, ozone, and aerosols) using an RB-57F which flies at altitudes of 60,000 feet. NASA is using a U-2 to determine the geographic and seasonal distribution of NO, O_3 and aerosols at altitudes of 60,000 to 70,000 feet. NASA is also developing a similar instrument package to be used routinely on commercial airliners for long term monitoring of the lower stratosphere and upper troposphere. Under development by NASA are small high altitude remote controlled aircraft to be used specifically for stratospheric sampling. Advanced instrumentation for satellite platforms is also under development for eventual use in routine global monitoring. The AEC studies the transport and composition of stratospheric aerosols routinely with RB-57F aircraft. Spectroscopic analysis of stratospheric constituents is being made by French, Belgian and British researchers with the aid of balloons and the Concorde prototypes. NASA is also using U-2 instrumentation to sample the exhaust of supersonic aircraft flying in the stratosphere. In general, the level of observing activity ongoing and planned is adequate for the level of sophistication of present instrumentation. The development of better instrumentation is the current bottleneck.

Extensive data are now becoming available regarding global ozone distributions. A fair amount of data are available regarding the distribution of dust particles and water vapor. Data are just now becoming available regarding nitrogen oxides and nitric acid. There are not yet sufficient data to provide an adequate base for model validation or long term monitoring.

It is reasonable to ask why extensive measurements are required. The answer is that nature continually provides surprises to trap the over confident investigator. For example, we know that ozone is produced by solar radiation. Hence, it is reasonable to assume (as it once was) that the ozone overburden would be greatest at the equator and least at the poles. It was found, however, that the reverse is actually true (figure 4); and this, of course, is one good reason why we now insist that transport must be accounted for properly in models. Man has been steadily polluting the stratosphere with products that should cause a slow but finite depletion of ozone; however, data accumulated over the past dozen years or more show a steady and significant increase in the total global ozone content--this, of course, is unexplained.

Intense controversy was produced by the first measurement of nitric oxide. Measured values varied from one investigator to another by as much as an order of magnitude. A continuing survey by NASA (figure 5) revealed that over the past 10 months the natural variation in nitric oxide levels varied by almost the same range. The reasons for these observations have yet to be explained, but no one would have thought it necessary to account for such variations if investigators had not been persistent in their probing of natural systems.

Hence we see that assessment activities are progressing but that techniques are still imperfect.

Control of Emission

Assessment of pollution effects tells us how bad things are or might be, but the advancement of air transportation technology requires solutions to the pollution threat that are politically viable. This means "cleaner" engines. We need to eliminate smoke on takeoff, reduce fuel odors and carbon monoxide concentrations around airports and minimize nitric oxides emitted during takeoff and cruise. The EPA is establishing required regulations and NASA has been aggressively developing technology.

The main components of the typical turbofan engine used on subsonic aircraft are a fan, compressor, combustor, and turbine. A portion of the air passing through the fan enters the compressor; the remainder of the air bypasses the core engine and provides part of the thrust. The compressed air enters the combustion chambers where fuel is sprayed and continuous combustion occurs. Hot gases exhaust into the turbine which drives the compressor and fan; the gases finally exhaust from the engine to provide the rest of the thrust. At low engine speeds carbon monoxide and hydrocarbon emissions tend to be high because of ineffient combustion caused by low combustor air temperature and pressure and non-optimum fuel-air ratio. At full power, combustion efficiency is nearly 100 percent and negligible amounts of carbon monoxide and hydrocarbons are exhausted; however, the resulting high flame temperatures and relatively long residence times within the reaction zone of the combustor lead to the formation of nitric oxides. Flame temperatures and thus nitrogen oxide emissions increase significantly with increasing combustion inlet temperature (figure 6).

The engine designer seeking to reduce the pollution from engines finds himself in a dilemma. The unburned hydrocarbons and carbon monoxide that plague airport operations can be reduced by increasing engine temperature and gas residence time to promote complete combustion, but higher temperatures and residence times promote the production of nitric oxides. Hence, the designer must find a way to provide complete combustion at as low a reaction zone temperature as possible, and this is much easier to say than do. Part of the answer lies in improving the fuel distribution system. And in this regard, smoky exhausts have virtually been eliminated by reducing combustor primary zone fuel-air ratio and thus eliminating fuel-rich zones. Reductions in hydrocarbon and carbon monoxide emissions at low power (or idle) may be obtained by more finely atomizing the fuel that is sprayed into the combustor. Various air atomizing injectors are being studied to accomplish improved fuel atomization and distribution.

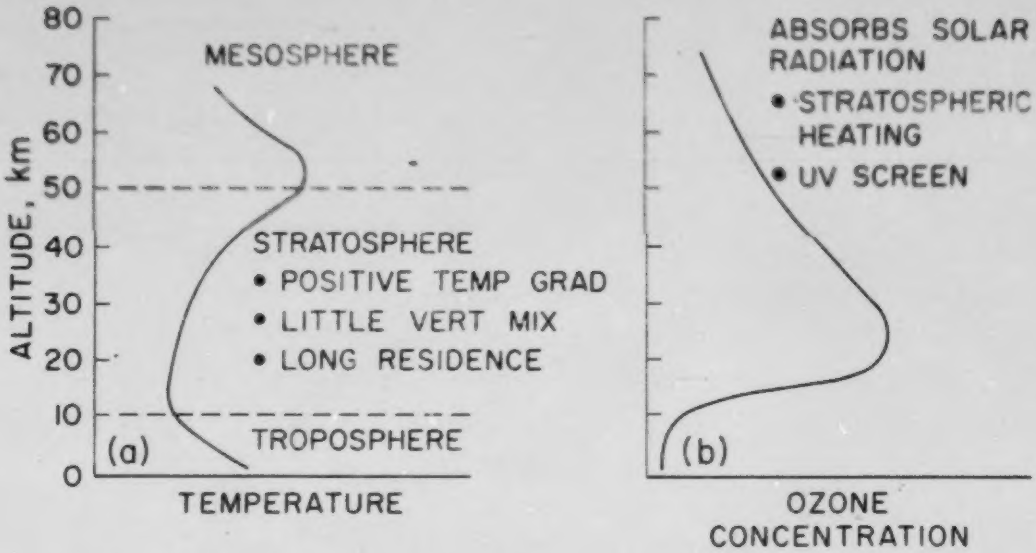
Reduction of nitric oxides produced at full power can be achieved by reducing the flame temperature and the times that gases reside in the hottest portions of the flame. This can be achieved by leaning the fuel-air mixture, premixing the fuel, and segmenting the flame zone. One concept which has resulted in reducing nitric oxide emissions to half is the swirl-can combustor developed at NASA's Lewis Research Center (figures 7 and 8). The approach results in the breakup of the flame zone into a large number of segments and features premixing the fuel and air, small burning zones, and rapid mixing with bypass air. The swirl-can combustor has had extensive testing. NASA is now engaged in an Experimental Clean Combustor Program in which jet engine manufacturers together with Lewis Research Center are exploring a number of new combustor designs. The best ideas will be selected for further refinement and, finally, the combustors will be installed in an engine and the emissions measured. The program is scheduled for completion in 1976.

Research is underway to develop ways of reducing the nitric oxide emissions by another order of magnitude. Analytical studies show that nitric oxides can be reduced substantially by burning a perfectly uniform fuel-air mixture at a very lean equivalence ratio. Prevaporizing and premixing the fuel with air upstream of the combustor should produce a uniform mixture. Flame tube studies of this approach show that 99% combustion efficiency can be achieved with less than one g of nitric oxides produced per kg of fuel burned during simulated supersonic cruise operating conditions; this can be compared with 18 to 20 g/kg produced in present day engines during similar operating conditions. Although theoretically possible, many practical problems remain to be solved before a premixing, prevaporizing combustor can be used in a gas-turbine engine.

CONCLUDING REMARKS

Today's assessment techniques are still relatively crude, but it is evident that there are good reasons to be concerned about the potential impact that aircraft operations might have on the environment. It may in fact be a long while before we can state with confidence that the impact will be trivial or profound. In the meanwhile it is politically necessary to work to develop cleaner engines so that advanced air transportation systems can be developed on an orderly and timely schedule.

Efforts are underway to develop both the assessment techniques and cleaner engines. A great deal of work remains to be done. These efforts require new ideas and sophisticated technology and, thus, should pose an exciting challenge for today's engineering and science students and graduates.



80
70
60
50
40
30
20
10
0
ALTITUDE, km
MESOSPHERE
STRATOSPHERE
• POSITIVE TEMP GRAD
• LITTLE VERT MIX
• LONG RESIDENCE
TROPOSPHERE
(a)
TEMPERATURE
ABSORBS SOLAR RADIATION
• STRATOSPHERIC HEATING
• UV SCREEN
(b)
OZONE CONCENTRATION

Figure 1.- Schematic profiles of stratospheric temperature and ozone concentrations.

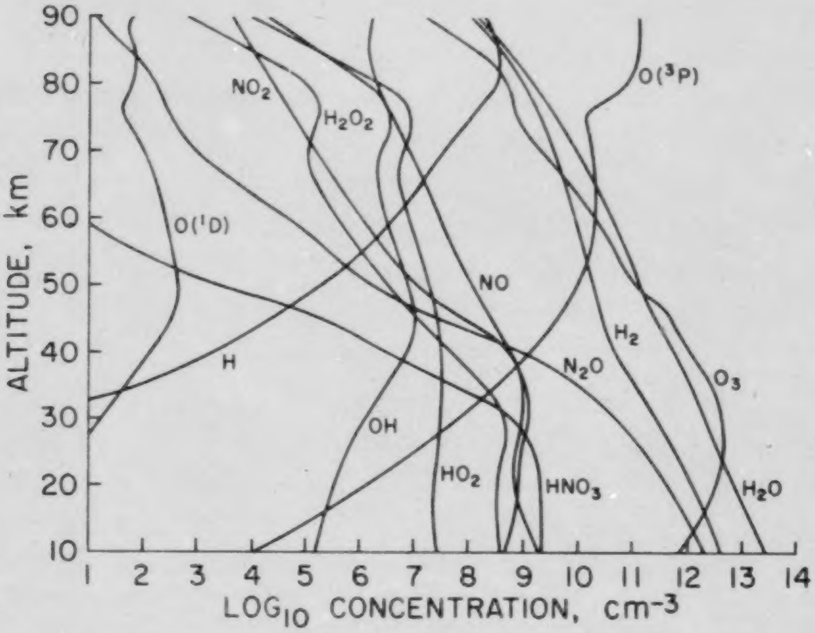


Figure 2.- One-dimensional model results. (Whitten and Turco, AIAA J., vol. 12, Aug. 1974, p. 1113.)

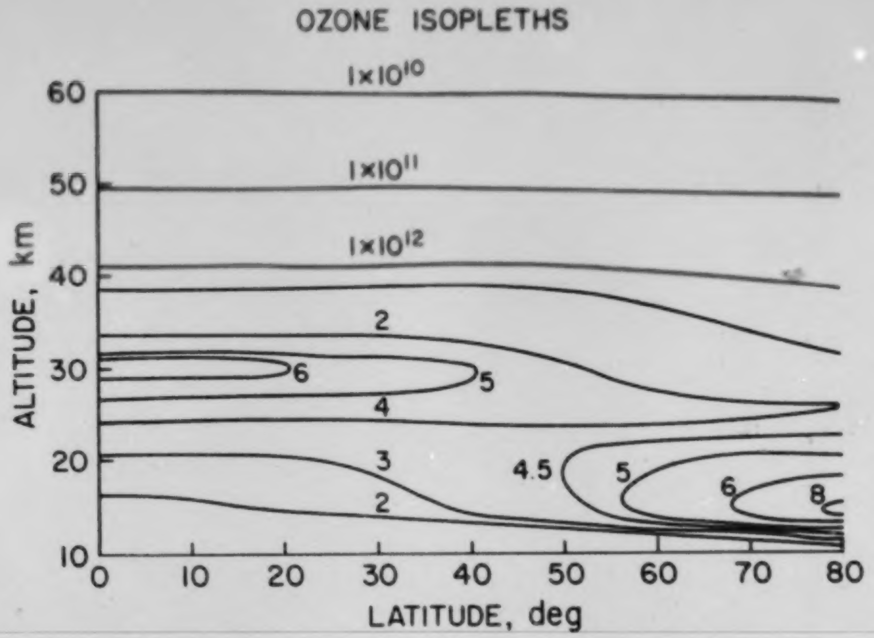
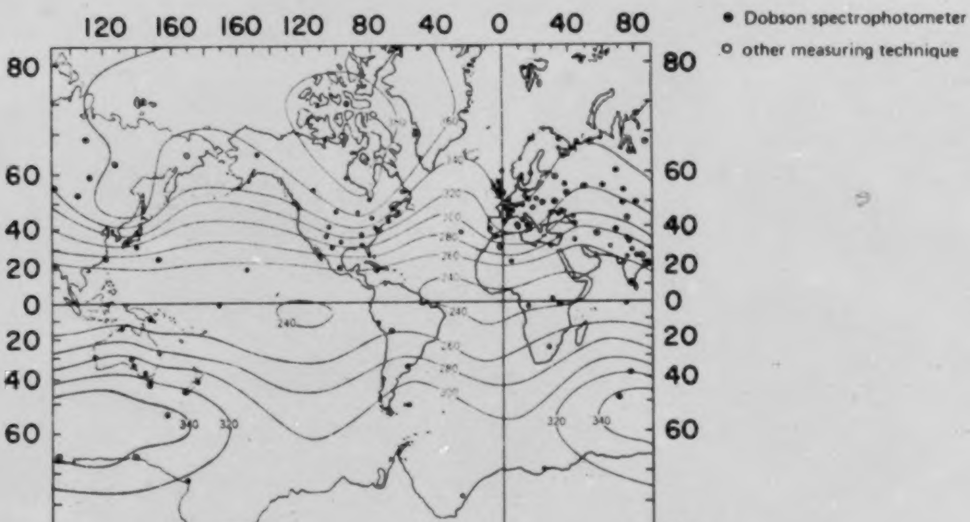


Figure 3.- Two-dimensional model results. (Whitten, et al., Ames Research Center, Oct. 1974.)


● Dobson spectrophotometer
○ other measuring technique
120 160 160 120 80 40 0 40 80
80
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80
240
260
280
300
320
340

Figure 4.- The global distribution of average annual total ozone for the period from July 1957 through June 1970 (values are given in milli-atmosphere centimeters). (London and Kelley, Science, vol. 184, May 31, 1974, p. 988.)

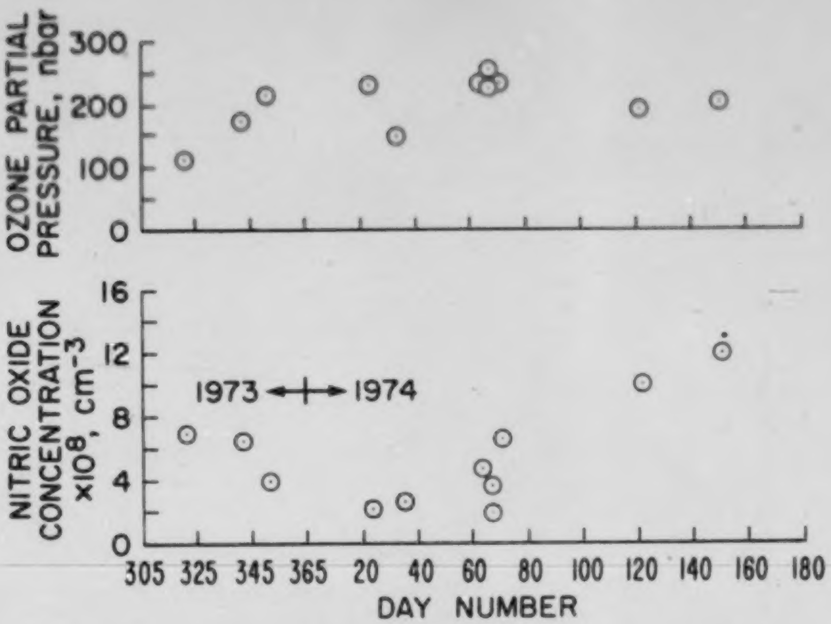

Figure 5.- Variations in the average NO and O_3 concentrations at 21.3-km altitude as a function of the day of the year.

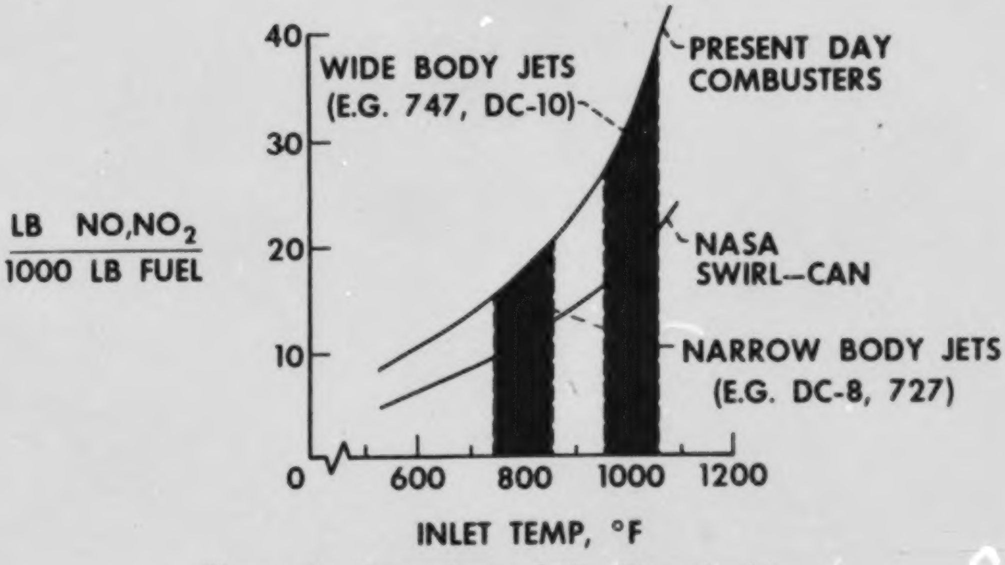

Figure 6.- Comparison of NO, NO_2 emissions.

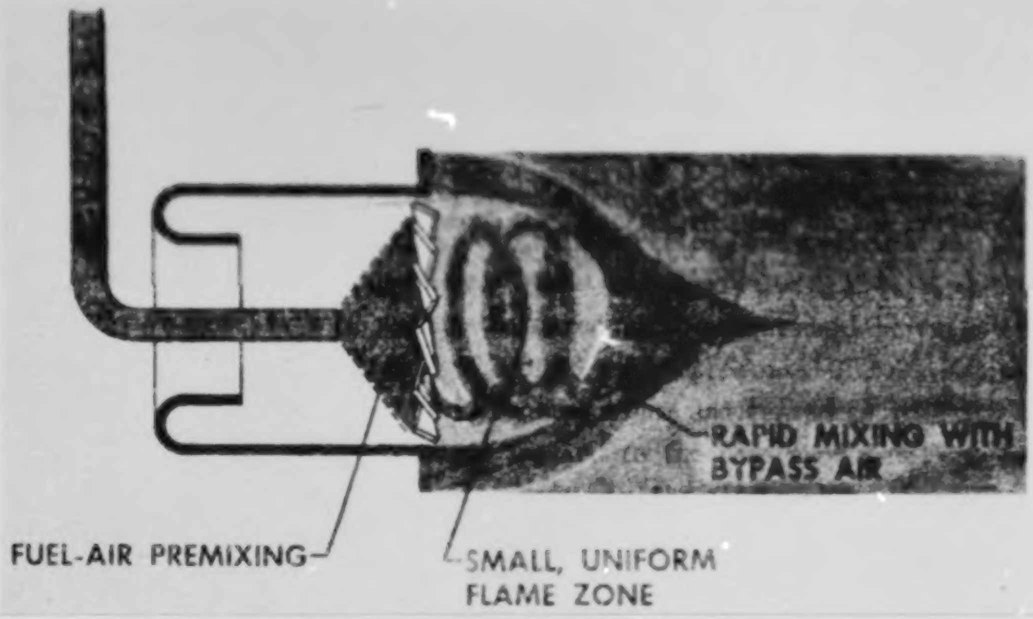
RAPID MIXING WITH BYPASS AIR
FUEL-AIR PREMIXING
SMALL, UNIFORM FLAME ZONE

Figure 7.- Swirl-can concept.

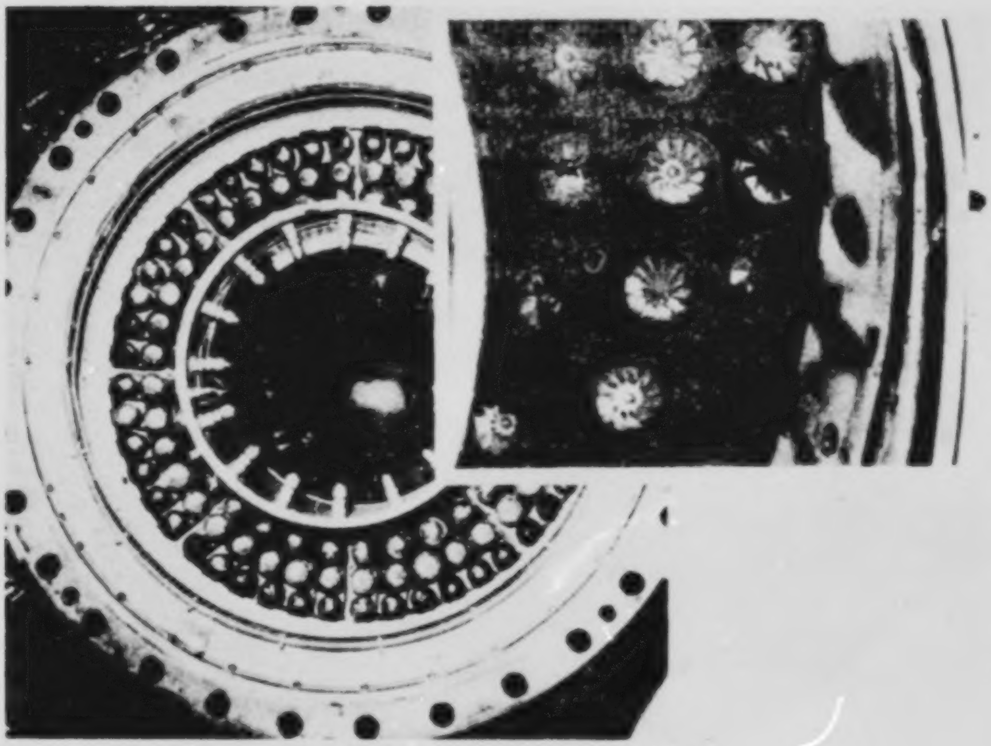

Figure 8.- Swirl-can combustor.

ON WAKE VORTEX ALLEVIATION

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SUMMARY

The paper reviews recent research within NASA relating to the nature of lift-induced vortex wakes behind large aircraft and the means whereby the hazard they represent to smaller aircraft can be alleviated. The research, carried out in ground-based facilities and in flight shows that more rapid dispersion of the wake can be effected by several means and that the modification of span loading by appropriate flap deflection holds promise of early practical application.

INTRODUCTION

The increasing size of modern aircraft and the increasing density of aircraft in the terminal airspace near major airports have combined to create a new problem to safe aircraft operations, the trailing vortex. The system of trailing vortices left in the wake of a large aircraft is a necessary consequence of its requirement to produce aerodynamic lift and has been the subject of theoretical and experimental research for a period of almost 50 years (a bibliography of the primary contributions to the subject is to be found at the end of this paper). The last 3 years, however, have seen a renewed effort to better understand and explain the basic aerodynamics of lift-induced vortex flows and to seek practical solutions which will reduce the potential hazard to smaller aircraft. It is the purpose of this paper to review some of the highlights of recent research in NASA and to suggest areas for further work.

SYMBOLS

x	distance in streamwise direction
y	distance in spanwise direction
z	distance in normal direction

9

r	radial distance from vortex center
b	aircraft semispan
t	time
V_θ	rotational velocity
U_∞	free stream velocity
V_{max}	maximum rotational velocity
C_L	lift coefficient
α	angle of attack

THE WAKE VORTEX HAZARD

The elements of the wake vortex problem are depicted in Figure 1. The wake is continuously created as a vortex sheet which rolls up into a pair of counter-rotating vortices. In practice, of course, the vortex pattern behind an aircraft is more complex than a simple vortex pair, and must be represented by a superposition of vortices generated by all lifting surfaces: the wing, the flaps and the fuselage.

The flow field behind the aircraft results in a downwash behind the wing span, and a corresponding upwash in the region outside the wing span causing a vortical flow emanating from each wing tip. Moreover, the circumferential velocity around the vortex core in turn produces a loss of pressure and a consequent flow along the axis of the vortex. The result is a highly disturbed region immediately behind the aircraft rather like two horizontal tornadoes with local velocities up to 50 miles per hour for a typical transport aircraft.

This vortex pattern is found to be quite stable and can exit with little decay for a distance of several miles behind the aircraft when the atmosphere is in a quiet condition (i.e., in the absence of strong winds or atmospheric turbulence). Ultimately the decay is determined by self-induced turbulence whose scale depends on the aircraft size and speed. This turbulence provides a mechanism for dispersing the vortex in a radial direction through diffusion so that ultimately the disturbance velocities are reduced to small values.

In contrast with our understanding of the near-field flow, our understanding of the mechanisms by which the vortex system decays is less satisfactory. Some recent theoretical work on the stability of a vortex pair in the presence of small disturbances shows that sinusoidal variations in the shape of the trailing vortex pair should be expected (the Crow instability) and this phenomena has been observed in flight. The phenomena of vortex bursting, wherein a sudden change in the vortex configuration due to an axial flow creates toroidal "smoke rings," has also been observed but there is conflicting evidence on whether this promotes rapid decay of the vortex.

If a small aircraft flies into the vortex wake generated by a much larger aircraft, loss of control or structural failure may result. For example, if the following aircraft flies directly up the core of the vortex, the induced velocities may impose rolling moments on the aircraft which are beyond the capability of its lateral control systems. If the following aircraft flies between the two vortices, the downwash velocities may cause loss of altitude and/or rate of climb capability. If the following aircraft flies across the vortex wake, the sudden changes in vertical velocity induced by the vortex may be large enough to cause structural failure. The vortex-induced disturbance can be particularly serious in the vicinity of large airports where separation distances between aircraft tend to be reduced and where small and large aircraft utilize the same airspace during takeoff and landing.

REDUCTION OF WAKE VORTEX EFFECTS

Inasmuch as the creation of a vortex wake is a necessary outcome of the requirement for the aircraft to produce lift, any attempt to reduce or destroy vorticity would be accompanied by a resulting loss of lift. The only practical approach to reducing the hazard, then, is to disperse the wake over a larger volume, thereby reducing the flow velocities and the associated rolling moment on a following aircraft. Most of the work currently underway within NASA is either directly or indirectly aimed at dispersion of the wake.

The several approaches being pursued are indicated in Figure 2 and can be characterized as:

(1) Modification of the wing span load distribution to avoid concentration of vorticity and promote radial diffusion of vorticity

(2) The introduction of turbulence into the wake through the installation of spoilers, or other drag devices, or the placement of engines, near the wing tip

and (3) The excitation of vortex instabilities by appropriate periodic motion of wing flaps or by design of the wing to promote self-excited unstable motions.

If, by one or more of these mechanisms, the intermixing of vorticity between the left and right wings can be achieved the wake will dissipate in a shorter distance behind the aircraft.

While all of the foregoing approaches have been studied to some extent, the one that appears to give the greatest promise of an early solution is the modification of span loading through the use of trailing-edge flaps. I will therefore devote most of my remarks to the research associated with this approach.

SOME HIGHLIGHTS OF RECENT RESEARCH

In recent years substantial progress has been made in understanding the basic aerodynamics of vortex flows both theoretically and experimentally. Our capability to calculate and to measure vortex flows has improved to the extent that it is now possible to associate the character of the wake with specific details of a wing planform. Moreover, the capability to measure, in flight, the wake vortex profiles behind large aircraft, through the use of hot-wire anemometers mounted on the nose boom of a probe aircraft, has provided us a valuable check on ground base results.

Let me illustrate first some results from our ground-based research. The span load distribution on a wing can be changed through appropriate selection of flap setting across the span. Shown in Figure 3 are several flap configurations for the same basic wing; the clean wing configuration and the normal landing configuration for a typical transport aircraft are shown in the upper half of the figure, and two modified flap settings labeled the tailored configuration to alleviate tip loading and the sawtooth configuration to promote vortex intermixing are shown below. These configurations have been analyzed theoretically and tested experimentally, and a great deal has been learned regarding the relationship between the span loading of the wing and vortex wake that is generated by the wing.

The ability to compare and graphically visualize the wake structure is illustrated in Figure 4, which shows the filamentary vortex lines for two differently loaded wings. The left-hand pattern is that for an elliptically loaded wing and shows a smooth roll-up of the vortex filaments into two separate tight vortices. The right-hand pattern shows the effect of imposing a sawtooth pattern on the elliptic loading by alternate upward and downward deflection of the trailing-edge flaps. The resulting wake is unstable to small perturbations and quickly breaks up into pairs of orbiting vortices. This disorderly pattern results because the span loading has a number of discontinuous steps, corresponding to the flaps, which shed a series of discrete vortices rather than a continuous sheet. This prediction of pair formation and subsequent chaotic motion has been confirmed experimentally in a water tow tank using a wing with 7 flap segments on each side.

Ultimately, in the far field, perhaps several miles behind the aircraft, self-induced turbulent diffusion plays a dominant role. It is this phenomena which ultimately determines the rate of decay of the initial distribution of vorticity generated by the wing. Some recent theoretical work, in conjunction with experimental research using large wind tunnels and towing tank facilities, has provided us with sufficient understanding to be able to characterize the turbulent decay of the vortex flow at far distances behind an aircraft. Some of the results of this work are illustrated in Figure 5.

The rotational component of velocity is shown here for a vortex formed behind a wing. The velocity profile is characteristic of that found in many of our experiments and exhibits a rapid rise to a maximum velocity near the center of the vortex, a sudden reversal of velocity across the core, followed by a subsequent return to zero. The form of this characteristic profile is preserved as time after passage of the wing increases but the maximum velocity decays and the core diameter increases, indicating the spreading by diffusion of the vortex.

The results shown in this figure were obtained in the University of California water tow tank. The tank is 61 m long and permits the study of the vortex decay for an appreciable time after passage of the model. Results of a similar nature were also found at appropriate distances behind a wind tunnel model in the 40' by 80' wind tunnel at Ames Research Center.

I would like to digress for a moment to say something about the special measurement techniques that were developed to acquire accurate data on the vortex flow: The vortex created by an aircraft is not stationary but typically follows a meandering path behind the aircraft; this meandering also takes place behind a wind tunnel model or tow tank, of course, which makes accurate measurement very difficult. To overcome this problem two special measurement techniques were devised. The first for use in the wind tunnel was a rotating boom at the end of which was mounted a hot-wire anemometer capable of measuring three velocity components. This technique gives both the location of the vortex and the local variations of velocity in its vicinity.

The second instrument used for this purpose is the laser velocimeter. This instrument (Figure 6) provides a direct measurement of two velocity components by tracking the motion of dust or smoke particles in the flow as they cross the interference fringes of a split beam laser. The laser beam rapidly scans the flow and the optical system, which focuses the laser, also receives back-scattered light which is collected by a photo-multiplier and analyzed to give the velocity components of the flow. This technique gives very accurate measurements and has the advantage of being non-invasive; the instrumentation is mounted outside the test section and does not perturb the flow in any way.

As a result of a great deal of theoretical modeling and experimentation we currently have a picture of the vortex decay that is represented by Figure 7. Here the maximum rotational velocity, near the center of the vortex core, is shown in dimensionless form as a function of distance behind the wing. The upper curve and data are for a clean wing (i.e., no flap deflection) and indicate both the near field behavior with little decay and the far field behavior in which the maximum velocity decays as the inverse square root of the distance are in good agreement with the theory.

Also shown below are the data for the modified span loading (in which the flaps are set to redistribute the wing loading away from the wing tips). In this case the near-field rotational velocity is reduced by a factor of two and the far field by about 40%. Alternatively, in the far field, the same velocity is experienced at approximately half the distance; this would imply a safe separation distance of 3 miles as opposed to perhaps 6 miles behind a large transport aircraft.

Having described something of the theoretical and experimental research let me turn briefly to the flight experiments that are being conducted to verify, at full scale, the conclusions of our ground-based program. The flight experiments permit us to determine the validity of the scaling laws and also to assure ourselves that proposed solutions can in fact be implemented within practical operational constraints.

The technique used for making flight measurements is to fly a small instrumented, or probe, aircraft into the wake at various distances behind the large generating aircraft to measure the velocity components within the wake and to record the forces and moments experienced by the probe aircraft. The wake is marked by introducing "smoke" (a mineral oil) at the wing-tips and at the flap locations of the generating aircraft to permit a more accurate penetration of the wake by the probe aircraft.

The probe airplane that has been used most frequently for this purpose is shown in Figure 8. It is a Gates Lear Jet which has been extensively modified to carry research instrumentation. The nose boom shown here measures angle of attack, sideslip, airspeed and altitude, and also contains a three component hot-wire anemometry probe for high-frequency measurement of the wake velocities. Also recorded on the aircraft are the parameters that define the probe aircraft motion and the control surface deflections. This information permits the calculation of the force and moments experienced during wake penetration.

The smoke-marked wake, as seen from the ground, is shown in Figure 9, for two different flap configurations on a Boeing 747 aircraft. In the left-hand photograph the aircraft was flown with its landing flaps in the normal landing configuration; i.e., both inboard flaps and outboard flaps deflected 30°. The vortex from the outboard edge of the flap and the vortex from the wing tip combine to form a strong vortex which persists for about 7 miles behind the aircraft. The right-hand photograph shows the aircraft with the outboard flap raised and only the inboard flap deflected 30°. This flap configuration redistributes the span load so that less lift is generated by the outboard section. The structure of the wake is now seen to be different; the vortex from the outer edge of the inboard flap and the vortex from the tip do not combine but twist around each other and subsequently disperse rapidly. The organized wake extends only about 3 miles behind the aircraft in this case.

This flight program is continuing to explore other configurational effects on the behavior of the vortex wake. Such factors as landing gear and the degree of sideslip, which generates fuselage vorticity, introduce additional effects on the wake which are not yet clearly understood. These effects are being investigated in the wind tunnels in order to permit a detailed exploration of the changes in the flow field.

FUTURE RESEARCH

Recent results, while providing a vastly improved picture of the persistence and ultimate decay of lift-induced vortex flows, have not yet yielded a sufficiently good practical solution that can assure dispersion of the vortex wake under all flight conditions of interest. The tools for conducting further work are now well in hand, however, and can be applied with some confidence.

The ability to calculate the behavior of the vortex wake in the near field and the far field has been demonstrated for aircraft planforms of simple geometry and the methods used can and should be extended to more general flight configurations. The development of the laser velocimeter as a non-invasive diagnostic tool has greatly facilitated the accurate and detailed measurement of velocity components in both the wind tunnel and the water tank and constitutes a breakthrough for the experimental aerodynamicist. The further use of this device will undoubtedly contribute to our understanding of the turbulent decay processes within the wake (and to our better understanding of many other aerodynamic flows of interest). The means of validating, in flight, the results of ground-based research, have also been enhanced by the use of well-instrumented probe aircraft which can penetrate the smoke-marked wakes of large aircraft.

With these tools in hand, the researcher and aircraft designer can undertake additional efforts which are expected to produce practical solutions to the wake vortex problem. The effects of span loading through optimal flap deflection should be pursued more thoroughly as the most likely means, in the near term, of dispersing the trailing vortex wake. Similarly, the effects of engine placement and the use of spoilers or other wing attachments, to introduce turbulence into the wake as it is formed, deserve further research and may provide the means of further dispersing the wake. Finally, the excitation of the wake vortex with a view to introducing fluctuations which promote dispersion deserve further investigation in order to determine whether such an approach offers an alternative practical solution.

CONCLUDING REMARKS

This paper has provided a brief review of some of the highlights of NASA research into the aerodynamics of trailing vortex wakes. This research has been, and continues to be, pursued at several NASA Centers and complements other work sponsored by the Federal Aviation Administration on the detection of aircraft wakes from the ground. The results obtained thus far from these programs are sufficiently encouraging that practical engineering solutions for alleviation of the wake hazard are foreseen within the next two or three years. Furthermore, the improved understanding of the basic phenomena should permit the design of larger aircraft that will be capable of operation without compromising the safety of other aircraft in their vicinity.

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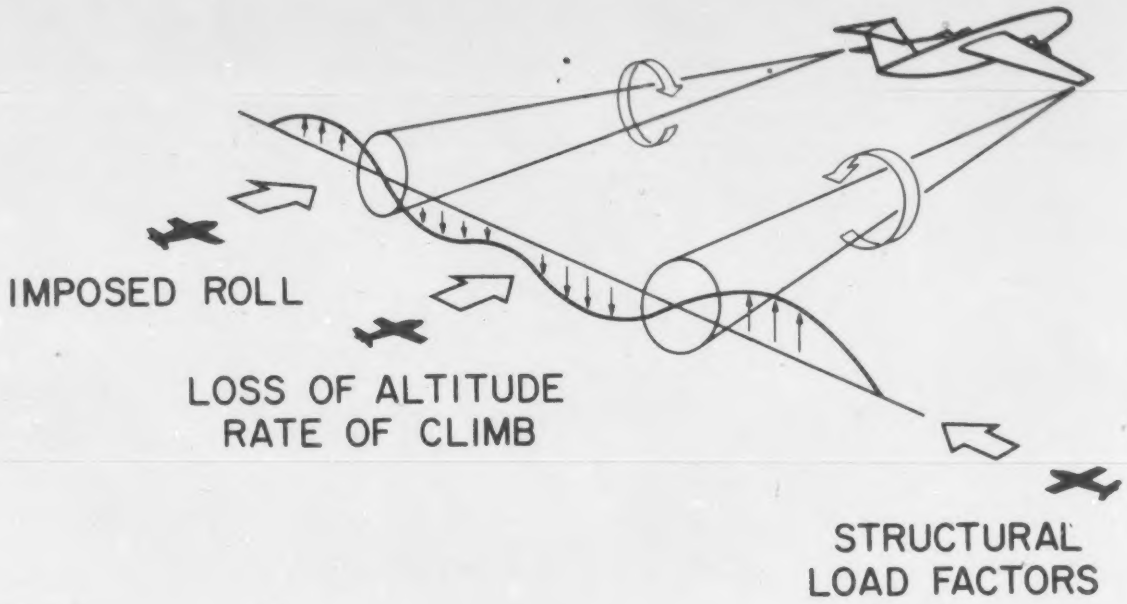
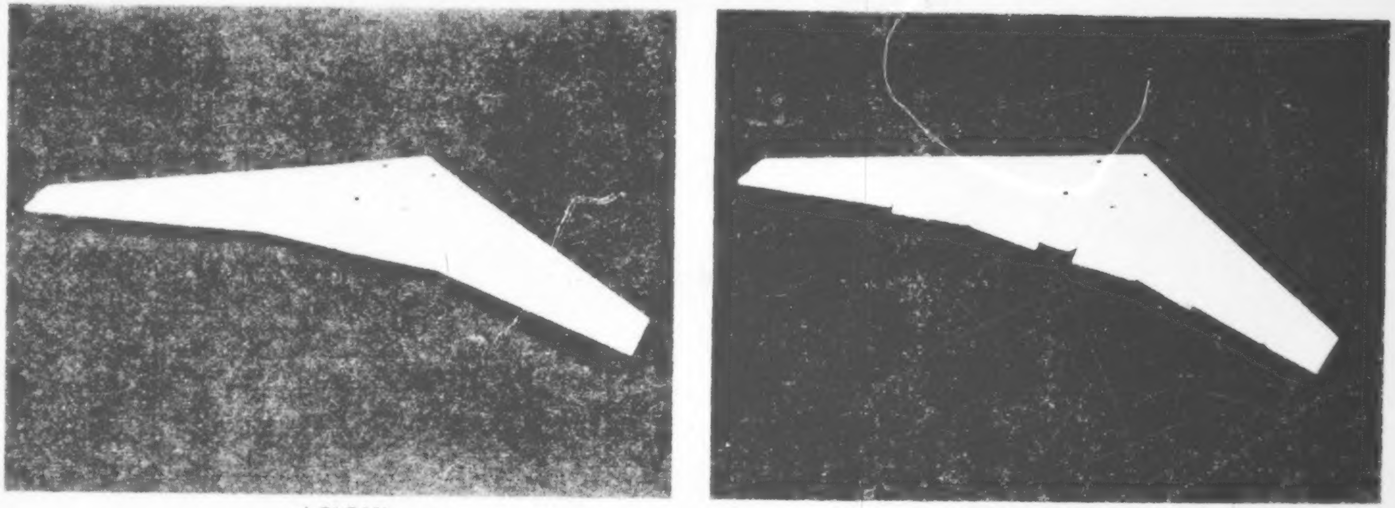

IMPOSED ROLL
LOSS OF ALTITUDE
RATE OF CLIMB
STRUCTURAL
LOAD FACTORS

Figure 1.- Wake vortex hazard.

- MODIFICATION OF SPAN LOADING
- INTRODUCTION OF TURBULENCE
- EXCITATION OF VORTEX INSTABILITIES

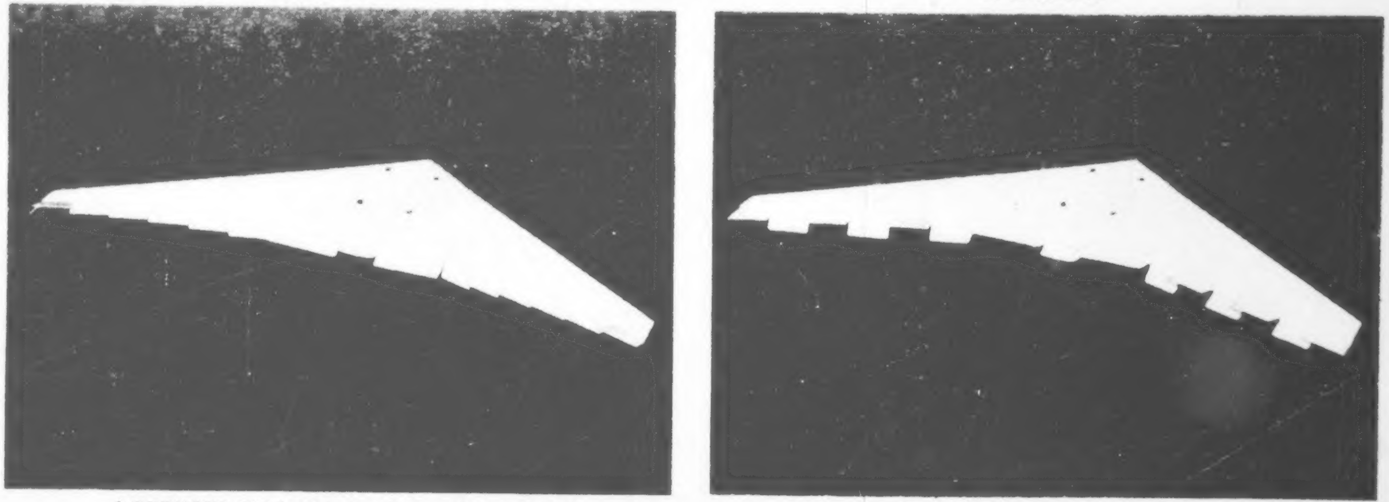
Figure 2.- Alternate approaches to wake dispersal.

SWEPTWING MODEL TEST CONFIGURATIONS



a) CLEAN

b) LANDING



c) REDUCED TIP LOAD GRADIENT (TAILORED)

d) MULTIPLE SPAN LOAD GRADIENTS (SAWTOOTH)

Figure 3.- Test model showing various flap deflection configurations.

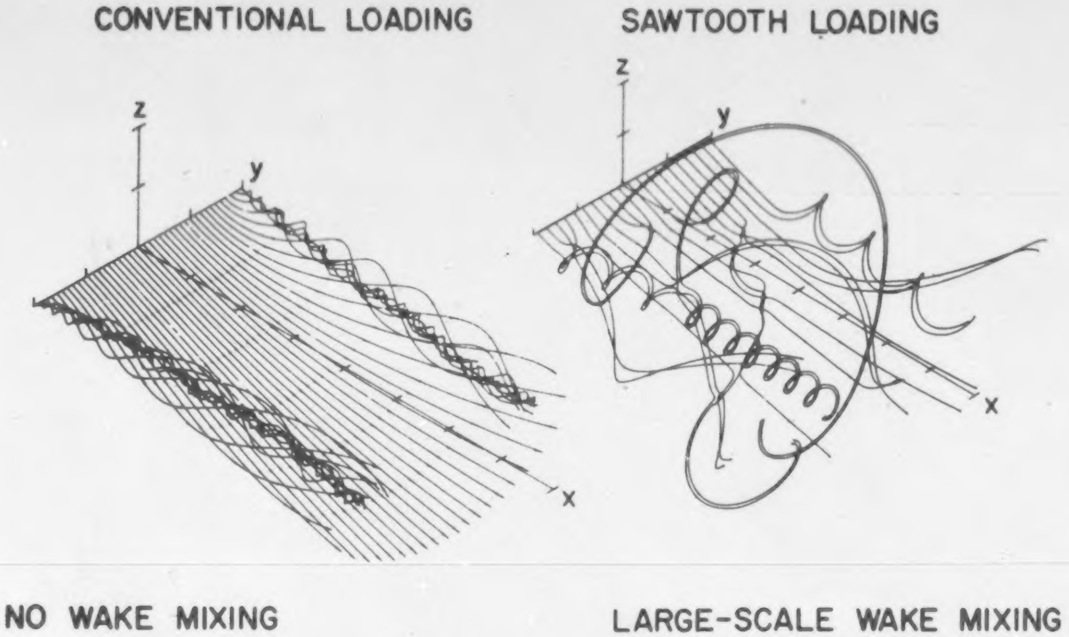

CONVENTIONAL LOADING
SAWTOOTH LOADING
z
y
x
z
y
x
NO WAKE MIXING
LARGE-SCALE WAKE MIXING

Figure 4.- Calculated wake structure for conventional and modified span loading.

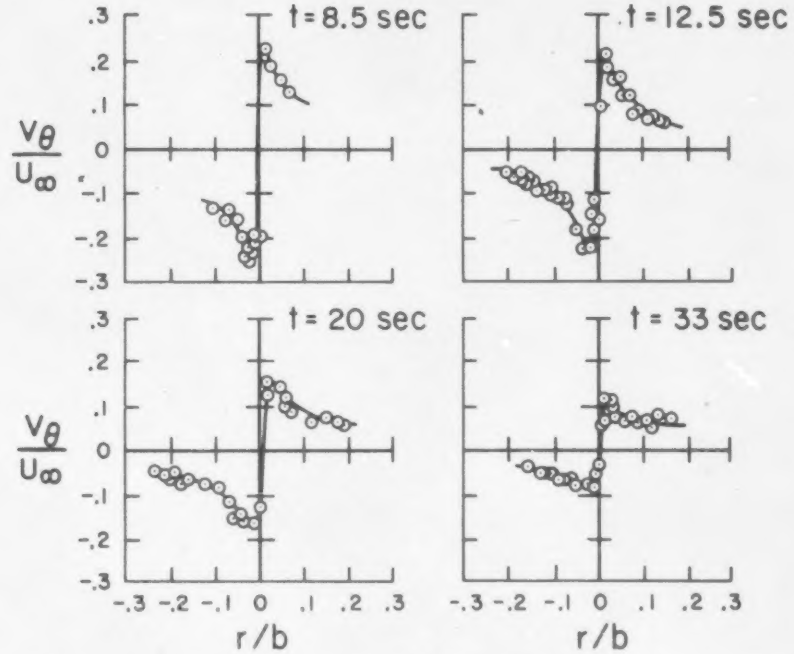


Figure 5.- Typical velocity distributions in the roll-up vortex as a function of time.

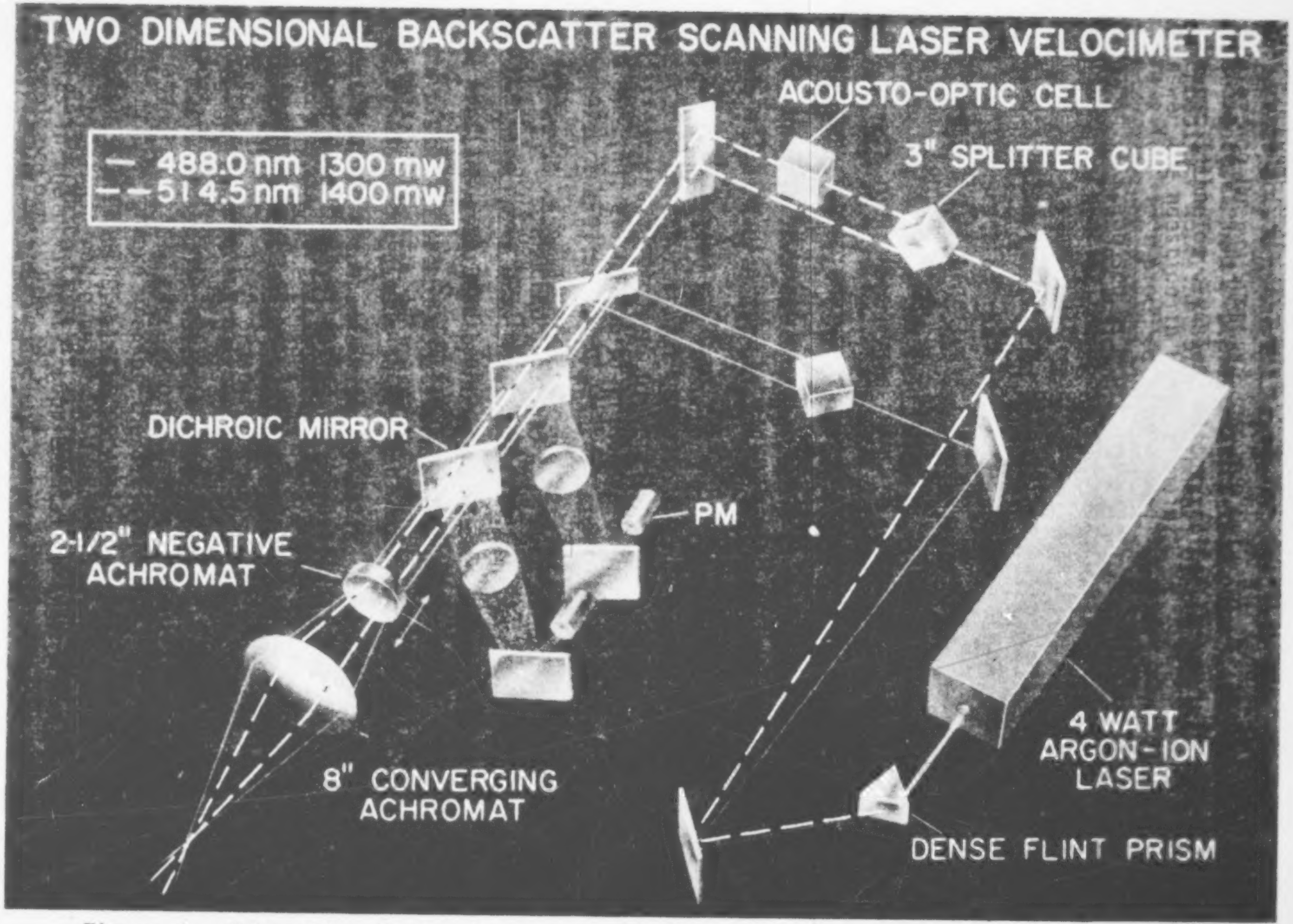

TWO DIMENSIONAL BACKSCATTER SCANNING LASER VELOCIMETER
— 488.0 nm 1300 mw
- - 514.5 nm 1400 mw
ACOUSTO-OPTIC CELL
3" SPLITTER CUBE
DICHROIC MIRROR
PM
2-1/2" NEGATIVE ACHROMAT
8" CONVERGING ACHROMAT
4 WATT ARGON-ION LASER
DENSE FLINT PRISM

Figure 6.- Schematic of scanning laser velocimeter (two velocity component system).

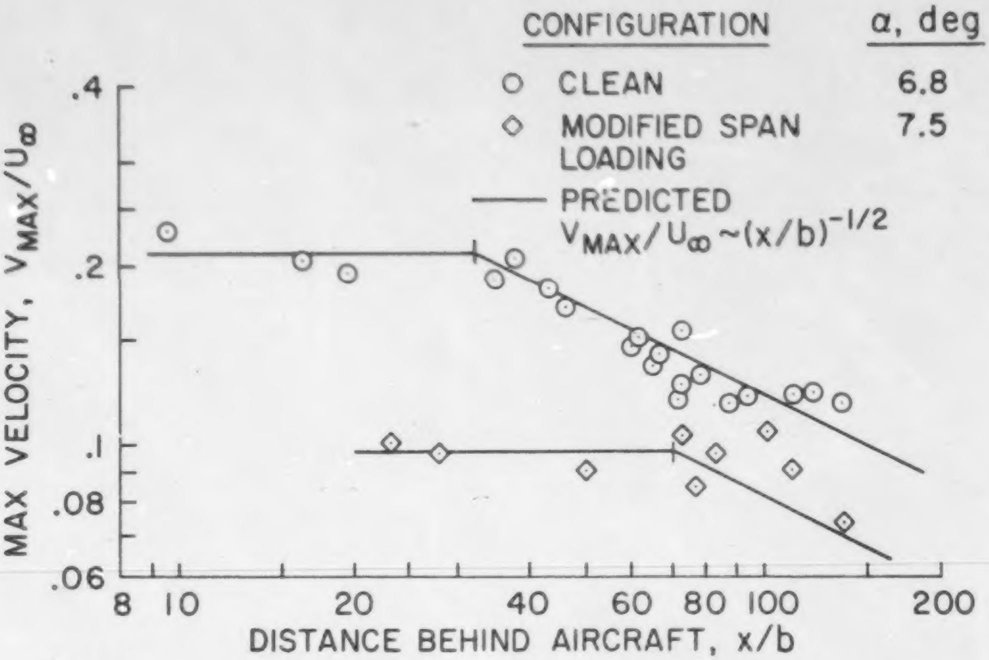


Figure 7.- Variation of maximum rotational velocity as a function of distance behind aircraft model.

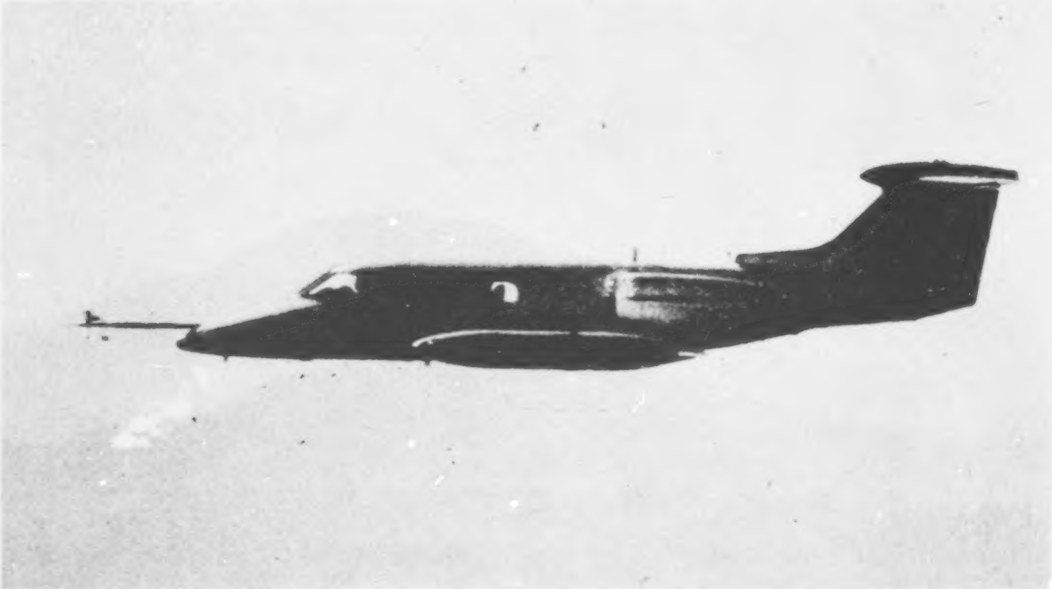


Figure 8.- Lear jet aircraft and instrumented probe carrying hot-wire anemometer.

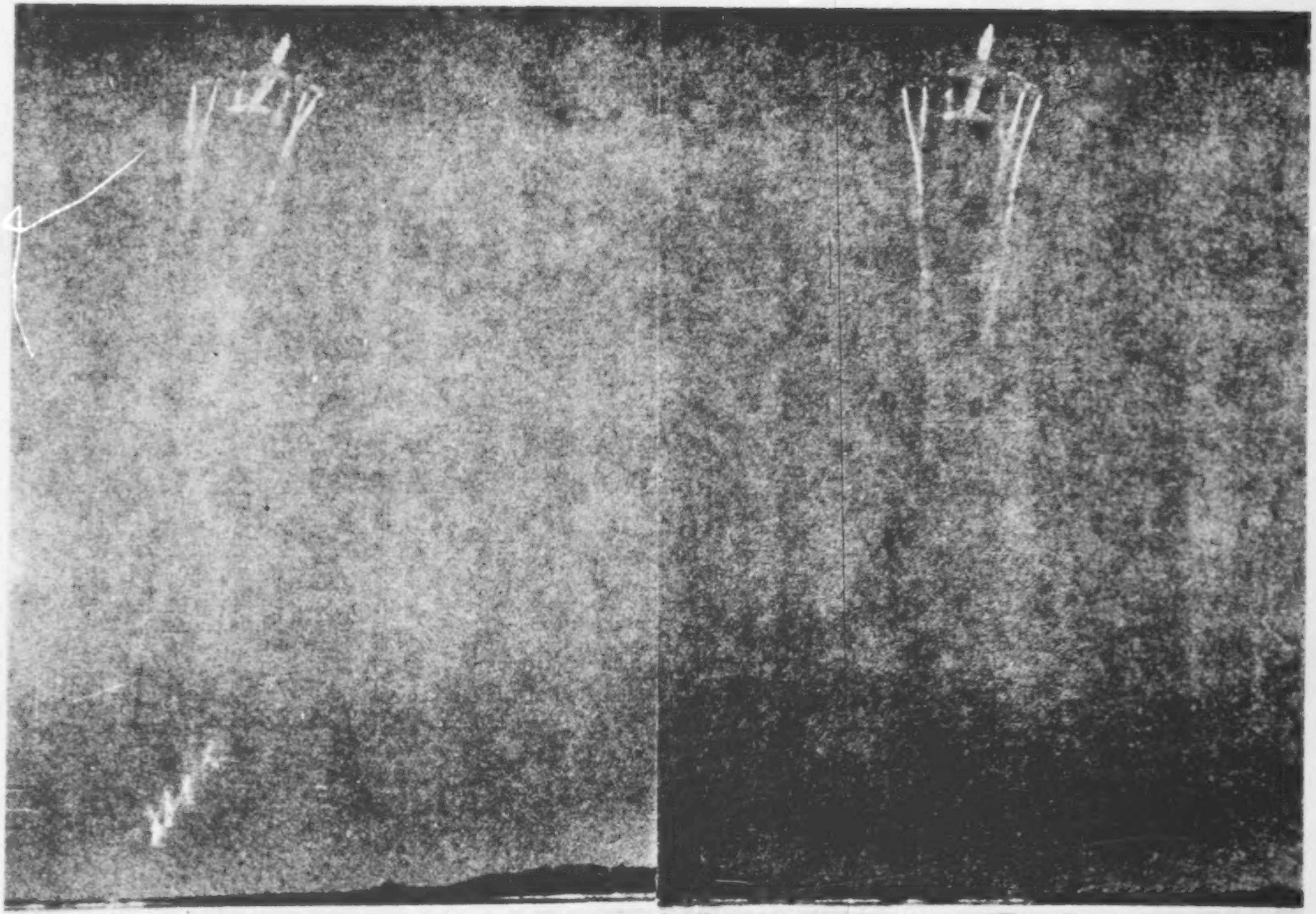


Figure 9.- Comparison of trailing vortex pattern behind Boeing 747 in flight. Inboard and outboard flaps deflected 30° (left); outboard flaps deflected 0° and inboard flaps deflected 30° (right).

AIRBORNE ELECTRONICS FOR AUTOMATED FLIGHT SYSTEMS

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SUMMARY

The increasing importance of airborne electronics for use in automated flight systems is briefly reviewed with attention to both basic aircraft control functions and flight management systems for operational use. The requirements for high levels of systems reliability are recognized. Design techniques are discussed and the areas of control systems, computing and communications are considered in terms of key technical problems and trends for their solution.

INTRODUCTION

Automated flight systems which are strongly dependent upon advances in airborne electronics are essential in order to make a number of significant improvements in the basic design and operation of future aircraft. In terms of basic aircraft design, effective application of automatic controls can yield increased performance and reduced structural weight. (See refs. 1 and 2.) Examples include control functions to permit relaxed static stability and obtain reduced trim drag; gust-load alleviation, maneuver-load alleviation, and flutter suppression to reduce weight and improve fatigue characteristics; and ride quality controls to increase passenger comfort. To achieve maximum benefit, these so-called "active control" concepts must be considered at the beginning of the design cycle since they will affect both the structural design and the configuration.

In a closely related manner, flight management systems will require increased levels of automation to permit efficient operational use. (See ref. 3.) For example, figure 1 indicates the functions which would be performed with advanced systems in a high-capacity terminal area. Precision flight-path control is needed so that the air traffic system can operate with increased capacity and reduced delays; optimal sequencing and flow control methods should be applied to conserve fuel; and automatic controls with appropriate monitoring systems and flight progress displays should result in important gains in schedule reliability under adverse weather conditions.

Some appreciation of the onboard computing task can be obtained simply by considering the flight paths indicated in figure 1. The type of display equipment which will probably be required is indicated in figure 2 which is a view of a research cockpit that is being used to study advanced operating methods.

There are many aspects to the design of both the advanced flight management systems and the automatic controls. However, the actual design and implementation of these systems in a reliable and cost-effective manner is probably the important issue. Airborne electronics, involving computers, sensors, actuators and even communications, must be designed with high levels of reliability and full consideration of maintenance and operational conditions over the service life of the aircraft. Reliability equal to that of the aircraft structure will be required for certain control functions.

It is recognized that technology is highly developed in terms of electronic devices and components and, although further advances will undoubtedly be important, emphasis must now be placed in the systems design area. Current research efforts such as the NASA Digital Fly-By-Wire, Active Control, and Terminal Configured Vehicle programs, along with related efforts in the Department of Transportation and Federal Aviation Administration on advanced air raffic management systems, are key factors in this process. With the assumption that these and other efforts in the aeronautical community will, in fact, determine the basic system concepts and requirements, it is appropriate to consider several technical areas where fundamental advances are needed in design techniques and systems implementation.

DESIGN METHODS

In many electronic systems, the problem of interdisciplinary design is becoming a key factor. Certainly, active controls represent one instance where this problem has been recognized for some time. In this case, it is important for the design team and, particularly, the electronic controls specialist to understand the fundamentals of the aerodynamics, controls, and structures which are involved. This is a most effective way to fully determine the requirements which are placed on the control system. Often a control specialist will find that his system must operate over a much wider range of conditions than might have originally been anticipated and that it is desirable to even consider adaptive techniques in order to maintain adequate control authority and acceptable handling qualitites.

Simulation techniques can be applied to insure that adequate attention is being given to the overall design integration problem. This permits difficulties in one discipline to be recognized and corrected at the proper point in the design cycle. It would be beneficial if universities could provide increased levels of experience in computer simulation of multidiscipline control design problems. One example is the use of the control system to alleviate structural loads and improve aircraft performance. Such a design obviously involves interactions and trades between aircraft performance, structural loads and weights, and control system complexity.

Another technique which is becoming increasingly useful is the application of parameter identification methods to explore the dynamics of a given system. This technique is illustrated in figure 3. Data from static tests in a wind tunnel are used to infer a number of dynamic derivatives. With this baseline condition, an aircraft or its model is flown and a wide range of measurements are made during the flight. A computer model is then used to duplicate the flight response with the coefficients selected to provide the best agreement with flight data. Increased exposure to parameter identification techniques would be helpful at the university level. For example, some of the techniques assume an idealized model with all errors subject to the limitations of Gaussian statistics. Insight into problems involving correlation, nonconvergence, and insensitivity is important in both theoretical and practical case studies.

CONTROL SYSTEMS

The speed and precision of the airborne digital computer are key factors in making possible the advances discussed earlier; however, complex hardware interface and software interactions require that control system design and implementation be carried out by using thorough analysis and testing. As an example, figure 4 shows a test system which has been built by using the airframe and control elements of an F-8 aircraft. Some insight into a typical control system problem can be provided by examining figure 5 which is a block diagram of the typical pitch-command augmentation system where a boundary controller and a direct lift controller are used with a normal controller and appropriate autopilot modes.

There is a need to place increased emphasis on the application of sampled data techniques in the control system design and to avoid the past tendency to conduct a conventional analog design and then perform a conversion to a digital system. Control laws and specific algorithms must be developed in a manner which is compatible with the basic architecture and software approach used in the flight computer.

The approach to design of the control system must also consider a wide range of redundancy management techniques which include the ability of the digital system to reorganize itself after failures or anomalies in individual elements, including motion sensors and control surface actuators. Such redundancy techniques should consider information which is available from dissimilar components as well as from hardware which is specifically duplicated. In a design problem of this type, advanced control theory must be exploited with emphasis on concepts such as nonlinear filtering, statistical hypothesis testing, and digital computing methods. A full appreciation is needed of the choices which are possible in control algorithms, processor organizations, sensors, actuators, and signal distribution techniques.

COMPUTING

Technology has advanced to the point where digital computers have become the obvious choice for complex control and flight management systems. Their precision, capacity, and speed make it possible to implement systems which could not be considered if one were restricted to analog methods. Achieving the required high levels of reliability is the principal issue in most system designs. Depending upon the function, the requirements may vary somewhat, but there is general agreement that critical control tasks must be performed so that basic system failure rates are on the order of 10^{-9} failure per flight hour.

Definition and analysis of system reliability is a very difficult and complex task; quantitative assessment of system performance with the tools that are now available can be misleading. In general, the reliability analyses have permitted comparative evaluations to select the superior approach rather than to yield a quantitative reliability assessment. With this understanding, figure 6 illustrates the problem which exists with today's computer systems. It is apparent that high levels of hardware complexity, or redundancy, are required to achieve the desired degree of reliability when hardware alone is considered. Another important factor emerges when the software aspects are considered in redundant systems which are necessarily complex. Current estimates indicate that the software in these complex systems can be up to two orders of magnitude less reliable than the hardware.

A number of efforts are underway to develop analytical and simulation techniques which will permit significant improvements in the evaluation of multiple computer configurations which employ redundancy and adaptability. As an illustration of progress in this area, figure 7 presents estimates of failure probability with a number of different multiple computer configurations for the case of a 10-hour flight mission. It is clear that only the more complex configurations begin to approach the levels of reliability which are desired, and it should also be noted that there are significant performance differences between different configurations employing the same number of computers.

With further development of reliability techniques which can accommodate both the software structure and the overall system architecture, it should be possible to conduct the type of evaluations which are needed for critical flight systems. Figure 8 illustrates one approach to this process. Here the analysis includes the systems failure criteria, software structure, and recovery and test features along with a definition of the fault environment in a specific configuration. Simulation and modeling are employed to validate the performance under various failure modes and to provide confidence in the fault-tolerance measures which result.

COMMUNICATIONS

Most aircraft communications needs have been met through the use of amplitude-modulated voice links operating in the very high frequency (VHF) portion of the spectrum. These voice links, along with the information transfer inherent in the radar tracking system, have been essential in order to control traffic flow and to maintain safe separations between all airline aircraft. However, in 1968 an advisory committee to the Department of Transportation recommended the development of a digital data link as a means of increasing communications capacity and alleviating certain operational problems. Recently, the airlines have worked toward a VHF data link capability and the Federal Aviation Administration (FAA) has been examining the use of a data link as part of the new Discrete Addressed Beacon System (DABS) being developed for air traffic surveillance. In addition, a digital data link is included in the development of the satellite system intended for use during transoceanic flight.

With the pending transfer of a number of important functions from the voice mode to a data link system, it is important to recognize the high degree of reliability that is required. This requirement results from the automated nature of this mode of communications, the fact that the confirmation aspects inherent to many voice exchanges are lost, and the reduction in supplemental information that the aircraft crew obtains by monitoring a designated channel. In addition to the requirement for high reliability, a data link should operate with minimum radiated power levels and spectrum occupancy because of the continually increasing demands on the electromagnetic spectrum.

One major factor which influences the degree of optimization that can be obtained with data link systems is the nonuniform radiation characteristics of conventional aircraft mounted antennas. Many of the current antenna designs provide coverage which is quite variable, depending upon the attitude of the aircraft. This is illustrated by the antenna patterns shown at the top of figure 9. It should be noted that there is a significant loss in coverage with the aircraft at a bank angle of 40°. Usually, it is possible to communicate but such communication requires the use of power levels on the order of 100 times greater than would otherwise be necessary. One method for improving this situation is to apply diversity techniques. The patterns at the bottom of figure 9 show the result with a dual frequency and polarization system which has been used at L band. In this case, overall communications reliability is on the order of 99.9 percent over a wide range of flight maneuvers.

Another important consideration with this type of communications is the multipath situation which is illustrated in figure 10. Because of the large number of paths which result from surface reflections, one encounters deep specular fades at low grazing angles and random interference at higher angles. Also, selective signal interference can result when data rates are high and the differential delay times due to multipath geometry are relatively large. Of course, the surface features are highly variable and result in a continuously changing set of process statistics for the noise and interference which are produced. The effect of these conditions is to greatly increase the error rates in high-speed digital links as compared with more ideal cases where reflections and antenna beamwidths can be controlled.

In an effort to explore solutions to the multipath problem, analysis and simulation studies have been performed on an adaptive receiving technique. In this approach, the receiver continuously makes an estimate of the characteristics of the noise and multipath interference and adapts a set of Kalman filters which operate with a probability decision unit to derive the output data stream. Figure 11 shows the results of one computer simulation. The error probability for the adaptive technique is given along with the results from standard detectors. It should be noted that the performance of the adaptive detector continues to improve with increasing signal to noise ratio while the conventional detectors saturate at a relatively high error rate. Although this particular approach may not be optimal, it is clear such techniques based on advanced information theory must be applied effectively in this class of communications problem if acceptable levels of reliability are to be obtained.

CONCLUDING REMARKS

Future aircraft will require increased use of automatic controls and new flight management systems which must be highly reliable and will involve extensive use of computing techniques along with important communications functions. In order to accomplish this type of electronic systems design, attention must be given to the multidisciplinary aspects of the problem, and increased use of simulation techniques and parameter identification methods will be important. With regard to flight control system, emphasis must be placed on the application of digital design methods and a full range of redundancy management techniques. Airborne computing systems must be designed and evaluated by use of advanced reliability assessment techniques which are only now being developed. Also, consideration must be given to the performance of communications systems with particular attention to antenna coverage problems and the application of advanced information theory to optimize digital data links.

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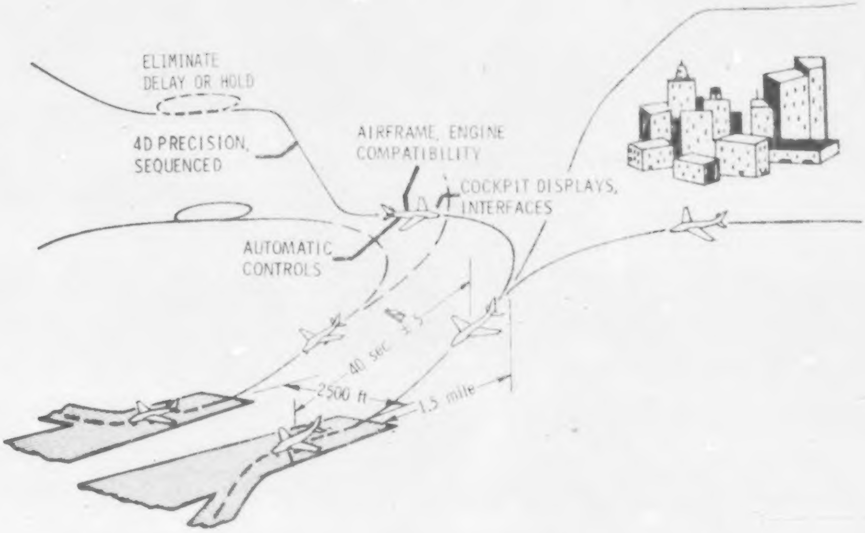
ELIMINATE
DELAY OR HOLD
4D PRECISION,
SEQUENCED
AIRFRAME, ENGINE
COMPATIBILITY
COCKPIT DISPLAYS,
INTERFACES
AUTOMATIC
CONTROLS
40 sec
2500 ft
1.5 mile

Figure 1.- High-capacity terminal area operations.

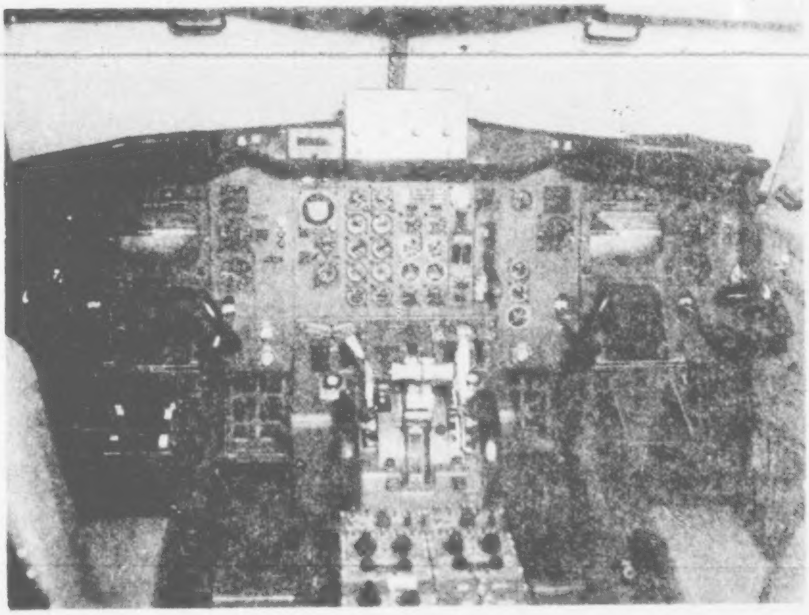

Figure 2.- Research cockpit.

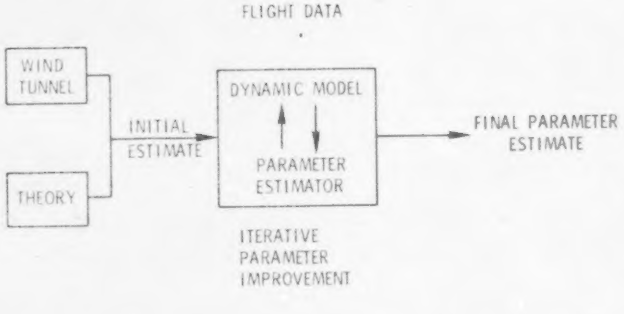
FLIGHT DATA
WIND TUNNEL
THEORY
INITIAL ESTIMATE
DYNAMIC MODEL
PARAMETER ESTIMATOR
FINAL PARAMETER ESTIMATE
ITERATIVE PARAMETER IMPROVEMENT

Figure 3.- Parameter identification process.

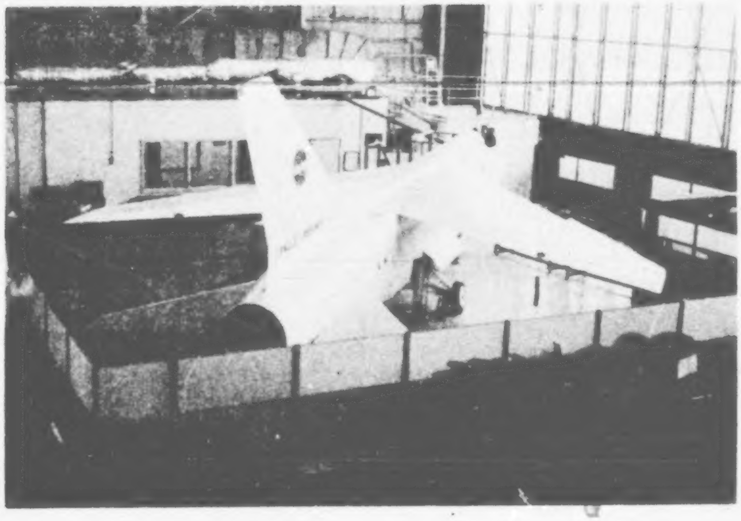

Figure 4.- Controls test system.

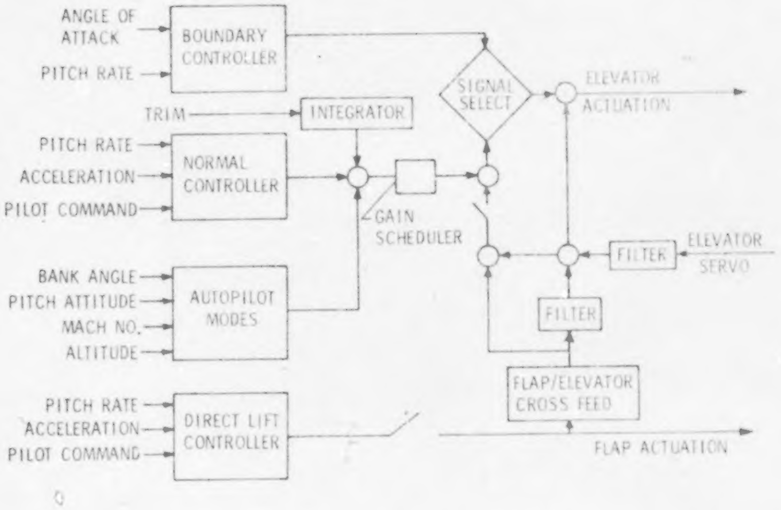
ANGLE OF ATTACK
PITCH RATE
BOUNDARY CONTROLLER
SIGNAL SELECT
ELEVATOR ACTUATION
TRIM
INTEGRATOR
PITCH RATE
ACCELERATION
PILOT COMMAND
NORMAL CONTROLLER
GAIN SCHEDULER
ELEVATOR SERVO
FILTER
FILTER
BANK ANGLE
PITCH ATTITUDE
MACH NO.
ALTITUDE
AUTOPILOT MODES
FLAP/ELEVATOR CROSS FEED
PITCH RATE
ACCELERATION
PILOT COMMAND
DIRECT LIFT CONTROLLER
FLAP ACTUATION

Figure 5.- Diagram of a pitch-command augmentation technique.

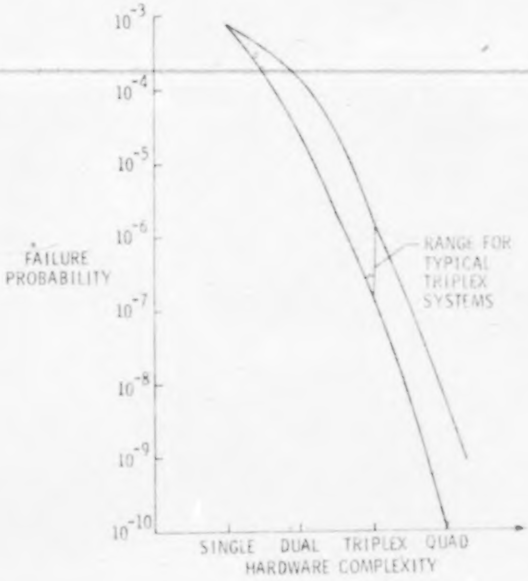

Figure 6.- Failure probability as a function of system complexity. Hardware failures only; 1-hr mission.

	CONFIGURATION	10-HOUR FAILURE PROBABILITY
5 COMPUTERS	QUINTUPLEX	$1(10)^{-9}$
	2 OUT OF 5	$6(10)^{-9}$
	(3 OUT OF 5)	$1.5(10)^{-6}$
4 COMPUTERS	QUADRUPLEX	$1.4(10)^{-7}$
	2 OUT OF 4	$7(10)^{-7}$
3 COMPUTERS	TRIPLEX	$2(10)^{-5}$
	(2 OUT OF 3)	$1.3(10)^{-4}$

Figure 7.- Typical effects of redundancy and adaptability in multiple computer configurations.

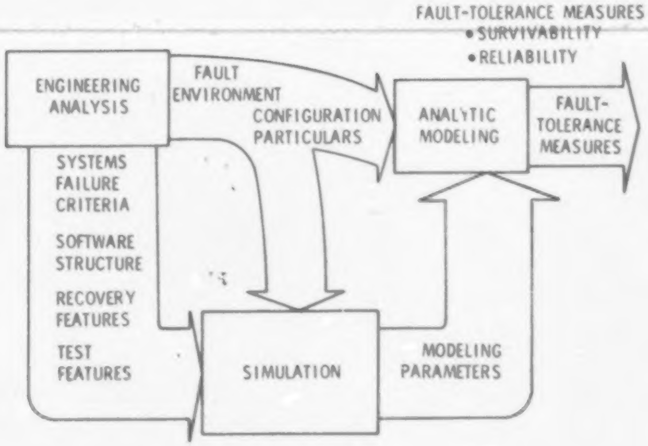
FAULT-TOLERANCE MEASURES
• SURVIVABILITY
• RELIABILITY
ENGINEERING ANALYSIS
FAULT ENVIRONMENT
CONFIGURATION PARTICULARS
ANALYTIC MODELING
FAULT-TOLERANCE MEASURES
SYSTEMS FAILURE CRITERIA
SOFTWARE STRUCTURE
RECOVERY FEATURES
TEST FEATURES
SIMULATION
MODELING PARAMETERS

Figure 8.- Approach to airborne computer system design evaluation.

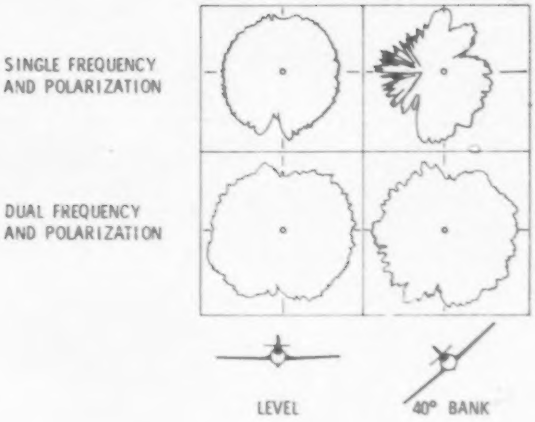

Figure 9.- Coverage with diversity technique.
Azimuth plane patterns.

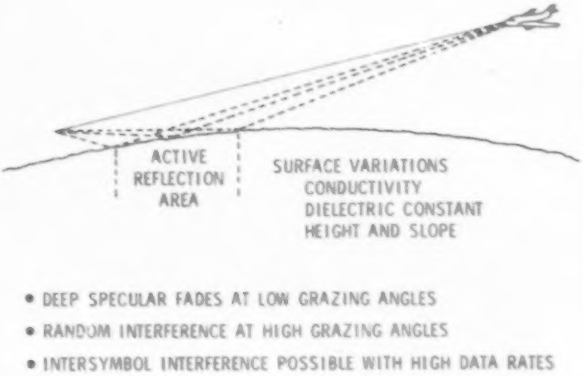
ACTIVE
REFLECTION
AREA
SURFACE VARIATIONS
CONDUCTIVITY
DIELECTRIC CONSTANT
HEIGHT AND SLOPE
• DEEP SPECULAR FADES AT LOW GRAZING ANGLES
• RANDOM INTERFERENCE AT HIGH GRAZING ANGLES
• INTERSYMBOL INTERFERENCE POSSIBLE WITH HIGH DATA RATES

Figure 10.- The multipath situation.

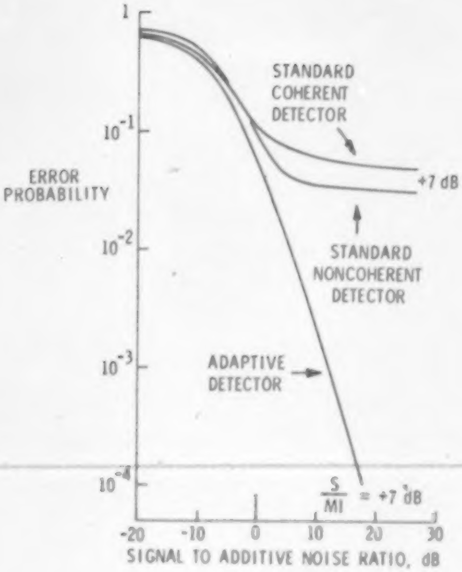

Figure 11.- Error rate of adaptive and standard detectors. 7-dB signal to interference; 2500 bits per second.

THE LONG TERM ENERGY PROBLEM AND AERONAUTICS

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ABSTRACT

The projected increase in energy consumption by transportation in general and civil aviation in particular is directly opposed to the dwindling supplies of natural petroleum crude oil currently used to produce aircraft fuels. This fact dictates the need to develop even more energy conservative aircraft and propulsion systems than are currently available and to explore the potential of alternative fuels to replace the current petroleum derived hydrocarbons. Advances in technology are described in the areas of improved component efficiency, aircraft and engine integration, control systems, and advanced lightweight materials that are needed to maximize performance and minimize fuel usage. Also, improved turbofan and unconventional engine cycles which can provide significant fuel usage reductions are described. These advancements must be accomplished within expected environmental constraints such as noise and pollution limits. Alternative fuels derived from oil shale and coal are described, and the possible technological advancements needed to use these fuels in aircraft engines are discussed and evaluated with relation to potential differences in fuel characteristics. The use of hydrogen as a future aircraft fuel is attractive from the standpoint of performance but the advances in technology required to economically produce and to effectively use this fuel would seem to indicate that its use for aircraft is in the far future.

INTRODUCTION

This paper describes some of the techniques that must be developed and employed to maintain the orderly growth of air transportation in the face of ever decreasing energy supplies. The aircraft, unlike some forms of transportation, is solely dependent upon the availability of fuels that are transportable and safe to handle. At present the fuel used in jet aircraft is a derivative of kerosene, which is refined from petroleum crude oil. The foreign oil embargo had a significant impact on the availability of all forms of petroleum based products such as gasoline, diesel fuel, jet aircraft fuel, home heating oils, and others. This produced the so-called energy crisis, crunch, or problem, depending on your particular point of view, and brought about a renewed emphasis on energy conservation, on the evaluation of energy resources that are available to all forms of users, and on whether projected supplies will satisfy the current and future demands. References 1 to 12 present the results of a variety of studies on this subject.

In attempting to project the future supply and demand, one must adopt some form of fuel usage estimate to use as a guide. The estimates used in the reference studies range from extremely optimistic to extremely pessimistic economic and technical growth projections. However, several factors are common in these studies. First, the breakdown of the current demand of energy users (table I) is a common starting point and secon., the projected percentage of energy demand by the prime users will be maintained at a reasonably constant level. This paper will not attempt to add to the many available fuel usage estimates but will instead utilize, in a simplistic fashion, information that indicates the potential magnitude of the problem for transportation in general and for aeronautics in particular. In doing this, a somewhat conservative viewpoint is used for projecting the fuel demand of aircraft. No large fleets of supersonic transports and no hypersonic vehicles are assumed to become commercially operable within this century. The projections used were mostly developed at the NASA Lewis Research Center.

In its simplest form, the technological answers to the future energy shortage and its impact on aeronautics can be found in two areas of activity: (1) Reducing the aircraft fuel consumption by employing advanced technology to improve the efficiency of the vehicle and the propulsion system, and (2) by increasing the amount of fuel available for aircraft by employing alternative types of fuel in the propulsion system. This paper describes the needs and projected advances that can be expected in these areas. More effective use of available aircraft load factors (increase in passenger seat miles per unit of expended energy) will also have a significant impact on efficient energy use in aeronautics. However, since this is an operational factor rather than a technical factor, it is not discussed in detail in this paper.

ENERGY DEMAND

When one considers the projection of overall demand for energy within the United States, the types of fuels that will be required to meet the overall demand is just as important as the types of users. Some users may be able to convert to alternative forms of energy whereas others may not. At present and in the foreseeable future, aircraft will be primarily dependent on petroleum derived fuels or similar alternative fuels. It is therefore important to view the energy problem and aeronautics in terms of available sources from which jet fuels, as we now know them, can be derived.

Projected Fuel Usage

The projected distribution of energy demand by fuel type is shown in figure 1. This projection, based on a NASA Lewis study, indicates a substantial increase in total energy demand and shows the expected increase in the energy demand for transportation. If one were to assume that all of the required energy needed for transportation would come from oil, over 50 percent of the demand for oil would be directly attributed to the needs of transportation. This percentage is projected to remain approximately constant until 2020. The energy demand distribution within the transportation sector is shown in figure 2. The overall level of the total fuel demand for transportation is projected to double in the next 50 years. This particular projection is somewhat conservative because of the assumptions used in projecting the demand for automobiles and aircraft. The actual energy demand (total Btu/yr) for automobiles is shown to remain nearly constant with time. This conclusion is based on the assumption that significant use of smaller cars will become prevalent, improved operations and maintenance will be employed, and demand for new automobiles will remain reasonably constant due to a low population growth. Of all forms of transportation considered, the energy demand for aircraft will experience the greatest relative change, approximately six times the current use. This factor of six is a conservative projection as illustrated in figure 3, where the Lewis projection is compared with larger aircraft growth rates from references 1 and 8. The differences are principally due to the Lewis' consideration of the following: (1) higher bypass ratio engines will be used; (2) flight speeds will be reduced by several percent; (3) passenger load factors will increase from current levels (≈50 percent) to near 80 percent; (4) the growth in air cargo will be only 50 to 75 percent of the optimistic projection; and (5) the introduction of supersonic transports will be delayed by up to 10 years from previous projections. This approach may seem extremely optimistic and it may well be that the actual demand will fall between the two projections.

Projected Supply Against Demand

The previous section discussed the growing fuel demand for transportation and particularly for aircraft. Depending on the assumptions used, aircraft energy demand is projected to increase from 6 to over 15 times its present use rate. Because aircraft are solely dependent on transportable energy, namely, fuel currently derived from oil, one must consider the projected oil supply against the projected demand in order to assess the potential magnitude of the problem. Figure 4 illustrates the projected supply against demand curve for two levels of domestic oil production. In evaluating the magnitude of the shortfall (difference between supply and demand) one can see a considerable difference as to the magnitude of the problem depending on whether domestic oil production can be increased with time. References 9 to 12 explain some of the reasons for the differences in the curves for the projected domestic oil production. These differences are principally related to economic and environmental constraints. Regardless of which supply projection is more accurate, the fact remains that a significant shortfall in our supply/demand situation is predicted to remain with us. At present this shortfall is offset by imported petroleum. Currently we are importing approximately 30 percent of our needs, and, depending on projections, this could go as high as 60 to 70 percent. This reliance on imported petroleum can become a crucial situation as the recent energy crisis has pointed out. With respect to aircraft and aeronautics, this petroleum shortfall is the primary energy problem. The technological approaches that we must follow to solve or at least reduce the problem are simply (1) to reduce the amount of fuel consumed by aircraft by improving the efficiency of our airplanes and propulsion systems and (2) to develop alternate fuels that can be used to supplement the current dependency on petroleum. The ways that we can minimize fuel consumption and increase fuel availability will be the emphasis of the remainder of this paper.

AIRCRAFT FUEL CONSUMPTION

There are many methods whereby aircraft fuel consumption can be minimized. Perhaps the most expedient method is to improve the operational procedures of air travel through reducing ground access time, better fuel management control during descent, approach, and landing, all-weather operations, reducing flight separation, and managing better all terminal operations. To accomplish these improvements will require technological advances in the fields of avionics and improved guidance and control systems.

The introduction of short take-off and landing (STOL) aircraft could have a significant effect on conserving energy in the airport areas. However, reducing the amount of fuel consumed during cruise by the large commercial conventional take-off and landing (CTOL) aircraft represents the greatest challenge since this mode of operation can account for up to 90 percent of the fuel used by aircraft.

Fuel Consumption Sensitivity

To ascertain where the technical impetus ought to be in approaching the fuel consumption problem, one must consider the relative effects that can be expected from aircraft/engine system improvements. The sensitivity of fuel consumption to improvements in four aircraft and engine performance parameters is shown in figure 5. Each parameter is plotted in terms of the projected fuel reduction as a function of the degree of parameter improvement for a DC-10 class rubber airplane on a 5560-kilometer (3000-n mi) flight. The term "rubber airplane" denotes an aircraft that has been designed to optimize the particular parameter being studied (e.g., specific fuel consumption). The fuel reductions indicated on this figure would be less pronounced if the study parameters were varied on an existing aircraft, but, the relative importance of the parameters would still be similar. Reducing both the empty weight of the aircraft and the installed weight of the engine can result in significant fuel savings. But reducing engine specific fuel consumption, SFC, (mass of fuel burned per hour per unit of engine thrust) and aircraft aerodynamic efficiency (lift to drag ratio) are the most significant parameters with engine SFC having the greatest effect.

Because improved aircraft design as an approach to fuel conservation will be covered in another paper at this conference, the paper will concentrate on improvements in engine and propulsion system performance. In general, engine changes are easier than aircraft changes and, since SFC is the prime parameter for reducing engine fuel consumption, technological developments required to improve this parameter will be emphasized.

Trends in Specific Fuel Consumption

Figure 6 (ref. 13) illustrates the trend in relative cruise fuel consumption of aircraft jet engines with time. The current second generation turbofan engines have achieved fuel consumption reductions approaching 40 percent lower than turbojet engines which were the first type of jet engine to be used in the commercial jet fleet. These second generation turbofan engines are currently being used on the wide-bodied jet aircraft (747, DC-10, and L1011), which are new in the fleet. A considerable portion of the aircraft in commercial service (727, DC-9, 707, 737, and DC-8) have first generation turbofan engines, and there are still some turbojet engines in service. A comparison of the basic features of these engines is shown in figure 7 and some of the prominent performance parameters dealing with fuel consumption are given in table II. The principal factors that have influenced this reduction in relative fuel consumption are the trend toward higher bypass ratios (ratio of the flow through the fan to the flow through the core engine; see fig. 7) higher overall compression ratios, and higher turbine-inlet temperatures. Improvements in component efficiency have also been important. Continued advances in these directions will lead to the future turbofan engine fuel consumption improvements indicated on figure 6. In addition to the projected improvements in advanced turbofan engines, the possibility of developing new engine cycles must also be considered. Since many of today's engines will still be in service for up to 15 or 20 years and since present technology may still be evident far beyond that period (35 yr or longer), our efforts must include fuel consumption reduction in current engines as well as advanced turbofan engines and unconventional cycle engines.

Current Engines

One problem of engines in current service is the deterioration of performance with time. Some of the first generation type turbofans have experienced increases in specific fuel consumption of 3 to 5 percent after a few thousand hours of service. Proper identification of the cause of this deterioration and appropriate maintenance or repair can usually restore this performance. However, we must properly identify principal culprits in the deterioration process and develop or apply technology to correct the deficiency. Better diagnostic procedures, better internal seals, and better materials that resist deterioration are and will continue to be needed.

A significant reduction in fuel consumption can be achieved by improving component performance. The component changes can be used in retro-fitting and in the future manufacture of current engines. The level of fuel usage reduction that can be expected (using a typical current turbofan engine cycle as a reference) by improving component technology are indicated in table III. These levels indicate improvements that could be achieved without varying engine cycle parameters, such as pressure ratio, bypass ratio, or turbine inlet temperature. These improvements in fuel consumption could be achieved by the replacement of components in existing engines and would not necessarily require new engine designs or new aircraft designs. All of the performance improvements indicated for the engine components (compressors, fans, combustor, turbine) and for the seals are achievable through continued technology developments such as those indicated in references 14 to 22. Improving installation effects from inlets and exhaust nozzles can also have a dramatic effect on fuel consumption but are very difficult to achieve; technological advances in this area are also being explored (ref. 14). Improved controls for better fuel management will probably lead toward the use of electronic fuel controls which are currently in the early phases of development. Low weight materials, such as composites, are also needed. Improvements in all of these areas must receive continued emphasis if we are to accomplish reduced fuel usage for current and future aircraft.

Advanced Turbofan Engines

In addition to the technology development areas already described, significant improvements in fuel usage can be accomplished by optimization of the turbofan engine cycle as indicated in figure 8. This figure uses a baseline turbofan engine with a bypass ratio of 6.9 and pressure ratio of 26 as a reference. The change in relative specific fuel consumption (1.0 being the reference point) as functions of engine bypass ratio and pressure ratio and the resultant changes in relative thrust per unit of engine airflow are shown. Significant fuel consumption reductions are indicated for both bypass ratio and overall pressure ratio increases; however, a penalty in relative thrust per pound of airflow is incurred. This penalty will require larger diameter engines (i.e., higher flow rate) to provide the same equivalent thrust of a lower bypass ratio engine; therefore, lightweight, high strength materials will be needed to keep engine weight down and realize all of the benefits indicated. In addition, the larger frontal areas of these engines will have to be considered when integrating them with an aircraft. Integration of engines and aircraft require trade-off studies to determine optimum design parameters between engine specific fuel consumption and aircraft design efficiency parameters such as lift to drag ratio (L/D). Some of these advanced components and materials that would be needed for this type of engine are shown along with a current engine in figure 9. These turbofan engine cycle advancements will have to be accomplished within the constraints on noise and pollution that will be required for all future engines. The larger bypass ratios will help reduce jet noise but the higher pressure ratio may increase some exhaust pollutants. The attendant energy savings that these advancements will provide make the high-pressure ratios high-bypass-ratio engine a most attractive area for aircraft engine development.

Unconventional Cycle Engines

In addition to the design variables already discussed, there are techniques whereby additional performance can be extracted from the basic gas turbine cycle. Techniques such as regeneration, intercooling, and reheat are currently being used in ground power type gas turbine engines, e.g., automotive and power generation gas turbines. A simplified schematic of the flow paths of a regenerative cycle turbofan is shown in figure 10. (See fig. 7 for conventional engine cycles.)

The method by which regeneration would be implemented into typical turbofan engine (as illustrated in fig. 10) emphasizes a need for high-performance (high heat transfer coefficient with low pressure drop), lightweight heat exchangers since they would be installed directly in the engine core gas flow path. The regenerator improves cycle efficiency by extracting heat from the turbine discharge flow, which would ordinarily be discharged through the engine exhaust nozzle, and using it to preheat the airflow entering the combustor. This preheated air allows less fuel to be used in the combustor to produce the energy needed to drive the turbine.

Gains in relative cruise specific fuel consumption that might be achievable by using regeneration in a turbofan engine cycle are indicated in figure 11. Reductions in specific fuel consumption up to 12 percent (depending on bypass ratio) are projected for a reference engine with an 1810 K (2800°F) turbine-inlet temperature. The "reference" value of 1.0 is a relative value for 1810 K (2800°F) (turbine-inlet temperature) that is independent of bypass ratio even though the absolute value of SFC varies. Because of this method of presentation, the reductions shown are attributable to the effect of regeneration only. A family of curves can be generated for various levels of turbine-inlet temperature which show that the highest potential gains are indicated for the higher turbine-inlet temperatures (assuming that major improvements in turbine cooling technology are attained). The potential level of reduction will also be dependent on the development of high performance, lightweight, durable heat exchangers.

The effective use of all of the techniques described in this section will require technology that does not currently exist but that does appear feasible.

AIRCRAFT FUEL AVAILABILITY

Since most conventional aircraft use a petroleum derived fuel, the approaches to reducing the projected fuel shortfall must naturally consider fuels that have similar, if not identical, hydrocarbon characteristics. Current jet fuels are primarily hydrocarbons of several molecular types, including paraffins, cycloparaffins, and aromatics. This terminology is used to describe the molecular structure (chain bonded, ring bonded, etc.) of particular hydrocarbon species that are contained in the fuel and, in general, is also descriptive of the hydrogen to carbon ratio of the hydrocarbon compounds. Paraffins and cycloparaffins are similar in most of their properties and together make up about 75 to 90 percent of most current aircraft fuels. They are stable, clean burning compounds. Aromatics are also stable but tend to be smoky in burning and are sometimes incompatible with elastomers. Reference 23 provides more detail regarding these and other hydrocarbon fuel molecular characteristics.

Many fractions of the crude oil are separated by means of distillation or refining whereby the light and heavy hydrocarbons are distributed into the desired boiling ranges for specific product requirements. A typical, current "split" of a barrel of crude oil into refined products is given in table IV. Only about 10 percent of a barrel is refined into the category known as kerosene from which most jet fuel is derived. This limitation can be partly attributed to the requirements of jet fuel specifications. Therefore, a possible short term approach to reducing the projected aircraft fuel shortfall would be to allow a greater yield of the barrel to be processed into jet fuel. This approach may also be necessary to provide for the projected increase in aircraft demand as compared to the other oil users as was shown in figure 2. There are, however, drawbacks to this approach. Possible safety hazards due to increased volatility and possible operational problems due to increasing the final boiling point of the fuel may be encountered. These factors could also influence the performance of combustors and fuel systems and would likely require modifications in these areas. But this approach does not supply additional fuel energy, and so does not reduce the overall projected oil shortfall. We must therefore explore the development and use of alternative hydrocarbon-based fuels and synthetic fuels that can be used to supplement the domestic petroleum supply. Even though imported petroleum is likely to be used to alleviate the shortfall in the foreseeable future, this dependence can be reduced through the use of alternative and synthetic fuels if we develop the required fuel and propulsion system technology.

Alternative Hydrocarbon Fuels

In this paper alternative hydrocarbon fuels are defined as those fuels refined from crude oils derived from oil shale, coal, and possibly other organics all of which are sometimes referred to as "syn-crudes." Prime emphasis is placed on crude oil derived from oil shale since shale is probably the most easily converted source of the so-called syn-crudes, and it most nearly duplicates the characteristics of petroleum. A projection of how the development of all three sources might affect the projected shortfall previously discussed is shown in figure 12. This figure illustrates the decrease in the level of the projected shortfall as a function of time, alternative fuel source, and investment dollars, and the level of petroleum supply projection. If one assumes that the high projection of domestic petroleum supply (fig. 12(a)) will be achieved, then it may be possible that supply and demand would be equalized before the year 2000. The low petroleum supply projection (fig. 12(b)) indicates that imported petroleum would always be required unless production of syn-crudes is increased (at greater cost). Bear in mind, however, that the demand curve shown is an optimistic (low) projection and, in the case of the contribution attributed to aeronautics, would require the implementation of some of the advanced technology that was discussed earlier in this paper.

The effective use of jet fuels refined from syn-crudes will depend on our ability to refine them to specifications similar to current jet fuels and/or to develop appropriate aircraft systems that could use them. Oil shale crude is is most amenable for jet engine fuel. Possible "off-spec" characteristics from coal derived crude oil with higher aromatic content could produce adverse effects such as smoky combustion, decreased combustor material durability, and unusual fuel deposits in current systems, and could require the development of advanced combustor and fuel system technology. There may also be some trace elements in the syn-crudes that may present problems not currently encountered with petroleum.

Before we can even consider using alternative fuels, effective means for retrieving the crude oils from their sources must be developed. Two techniques that are currently being explored are illustrated in figure 13. The oil shale process is of more interest in the near future. Efficient, economical crude oil retrieval developments, although not directly related to aeronautics, will certainly be required. The refinement of crude oils derived from these processes into usable aircraft fuels and the development of the engines and fuel systems to use them must be pursued and guided by technologists within the aeronautical sciences.

Synthetic Fuels

The most prominent synthetic fuel which has been considered for possible use on aircraft is hydrogen. There is nothing new in the suggested use of hydrogen as an aircraft fuel in as much as jet aircraft engines were successfully operated on hydrogen in the late 1950's (ref. 24). Since then, continuous study of this fuel and its impact on aircraft and propulsion system design has been underway. References 25 to 30 are just a small sample of these studies. Hydrogen's heat release or energy content per unit of mass is approximately three times that of hydrocarbon jet fuels. This increased heat release rate can result in significant savings in fuel weight, which in turn reduces aircraft gross takeoff weight, for a given payload, as illustrated in figure 14. The computed curves, as with others in this paper, are for rubber aircraft; in this case one that is optimized to utilize the best features of hydrogen fuel as compared with an aircraft designed to use a hydrocarbon fuel. Variations in aircraft takeoff gross weight are often used to indicate overall system efficiency because it implies the possibility of either increasing payload and/or flight range within a given take-off gross weight constraint.

In judging the likelihood of using hydrogen as an aircraft fuel, some of the disadvantages must be considered. First, it has a very low density even in a cryogenic form, which is the only feasible way that it could be used on an aircraft. This low density will require large tanks (approximately four times as large as current hydrocarbon fuel tanks for a comparable mission) and the cryogenic temperatures will require insulated tanks, fuel systems, and structures. These factors would have significant effect on the design of aircraft, and on the transporting, storing, and refueling activities that are necessary to supply aircraft at all of the airports serviced by our commercial fleets. In addition, the cost of hydrogen is not currently competitive with hydrocarbon jet fuels, although this consideration may become negligible with time. A very critical consideration in the potential use of hydrogen is that it takes approximately 3 to 5 times more energy (e.g., from electrolysis) to make liquid hydrogen than can be effectively extracted from it when used as a fuel. In terms of total energy consumption, this then would be an inefficient overall use of energy resources. All of these factors imply that a wide variety of advanced technology and socio-economic considerations must be explored to make hydrogen a viable aircraft fuel.

Even with these drawbacks, hydrogen has a number of advantages. It is a clean burning fuel and is capable of burning over a wide range of conditions, which may allow more advanced, high performance combustion systems to be used.

Although the engine fuel system may be complex (fig. 15) few propulsion system problems exist. Only minor improvements in engine and fuel system technology will be required (primarily in fuel pumps). Some of these are described in reference 30, which also summarizes some of the results of previous propulsion system studies.

Because it has the potential to provide relief to our projected fossil fuel supply/demand problem, continued development of advanced hydrogen propulsion technology is warranted for all classes of future aeronautical vehicles. Particular emphasis will likely be placed on very-high-speed flight vehicles (high supersonic and hypersonic) because the performance benefits are more pronounced at these speeds.

CONCLUDING REMARKS

Since aircraft are solely dependent on the use of a mobile, transportable fuel, the projected shortfall of energy derived from petroleum crude oil could significantly effect the projected growth of air transportation. Although this shortfall is currently being alleviated by the use of imported petroleum (≈30 percent of our oil is imported), the magnitude of the total oil shortfall will increase with time (possibly requiring up to 60 to 70 percent imported) thus making the aircraft industry extremely susceptible to an oil embargo such as was experienced in 1973. If we are to eliminate or at least minimize the impact of this type of action in the future, we must develop self-sufficiency by employing technological developments. Proper selection and development of advanced technology to reduce the fuel consumed by aircraft and to increase the availability of suitable alternative fuels that can be used by aircraft will be necessary.

The trend in aircraft and propulsion system development has been toward improving efficiency and thus reducing fuel consumption; even further technological developments in engine component performance, installed performance, controls, materials, seals, and maintenance as well as continued engine cycle optimization and consideration of unconventional engine cycles must and will be pursued. These efforts along with further improvements in aircraft aerodynamic performance and operation will produce a future air transportation system that is more fuel conservative than our current fleet.

Development of fuel sources other than petroleum will help to alleviate all or at least most of the projected shortfall between domestic oil supply and demand. We must insure that these fuels are compatible with the requirements of aircraft either by refining them to existing aircraft fuel specifications or by developing appropriate engines and fuel systems to utilize these fuels. The use of hydrogen as an aircraft fuel is attractive from a performance viewpoint, but will require significant technological developments and socio-economic considerations before it can be effectively and safely used on aircraft. It would appear that the use of hydrogen to alleviate the energy problem for aircraft is in the far future (well beyond the year 2000).

Reducing fuel consumption in aircraft is possible and implementation of advanced technology along with appropriate development of alternative fuel sources will provide the solution to the projected energy problem and its potential impact on aeronautics, thereby allowing a continued, orderly growth of air transportation. This goal can and will be accomplished with appropriate consideration for noise and pollution constraints which will be significant factors in all advanced propulsion system developments.

ACKNOWLEDGMENTS

In the preparation of this paper, considerable information was drawn from work compiled in unreported studies performed by members of the NASA Lewis Research Center's Power Systems Division and the Mission Analysis Branch of the Wind Tunnel and Flight Division. Without this information this paper could not have been written.

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TABLE I. - U. S. ENERGY DEMANDS IN 1970

	Energy demand		Percent of total demand
	J/yr	Btu/yr	
Transportation	17.3×10^{18}	16.4×10^{15}	24
Power	17.4	16.5	24
Buildings	13.6	12.9	20
Industry	22.8	21.6	32

TABLE II. - ENGINE CYCLE PARAMETER COMPARISONS

Type of engine	Bypass ratio	Maximum turbine-inlet temperature		Maximum pressure ratio	Relative fuel consumption, SFC/SFC_{ref}
		K	°F		
Turbojet	0	1260	1800	12	[a]1.0
First generation turbofan	1	1310	1900	16	.8
Second generation turbofan	5	1420-1540	2100-2300	25	.6
Advanced turbofans	10-15	1920-2020	3000-3200	30-40	0.4-0.6

[a]Reference value.

TABLE III. - POSSIBLE IMPROVEMENTS TO CURRENT HIGH-BYPASS-RATIO TURBOFAN ENGINES AND THEIR EFFECT ON FUEL CONSUMPTION

[DC-10 class aircraft on 5560-km (3000-n. m.) mission.]

Component	Improvement	Fuel usage reduction, percent
Compressor	1% Increase in aerodynamic efficiency	1
Fan	2% Increase in aerodynamic efficiency	2
Combustor	1% Less ΔP and improved off-design efficiency	1.5
Turbine	1% Less cooling air	1
Seals	Ten times less leakage	2
Installation	1/2% Increase in inlet recovery	1.5
	1% Increase in nozzle coefficient	3.5
Controls	Improved fuel management	3
Materials	20% Less engine weight	4

TABLE IV. - CURRENT PRODUCT DISTRIBUTION FROM A BARREL OF PETROLEUM

Products (first cut)	Percent yield	Products (additional refining)	Percent yield
Liquid petroleum	3	Liquid petroleum gas and petrochemicals	7
Gasoline	27	Gasoline	45
Kerosene	10	Jet fuel	10
Gas oil	40	Diesel oil, home heating & fuel oils (various grades)	32
Residuals	20	Lubrication oil, asphalt, coke	6

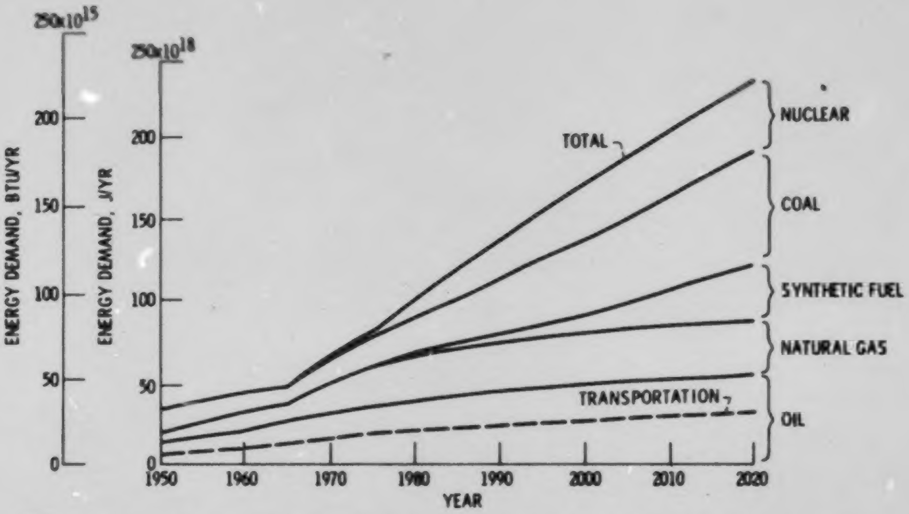


Figure 1.- U.S. annual total energy projection by fuel type (Lewis projection, March 1974).

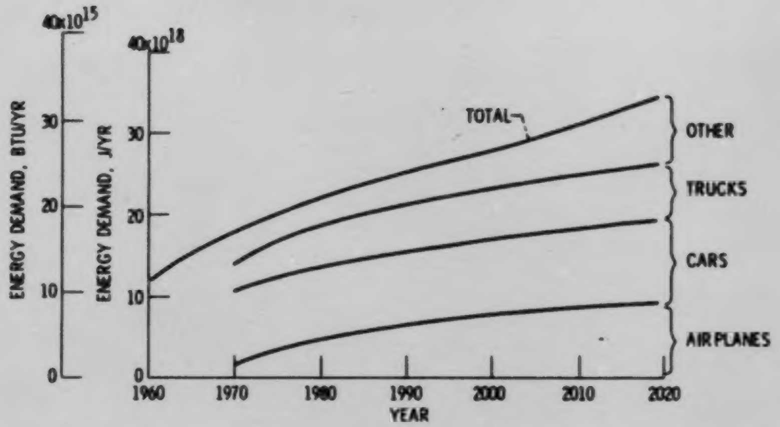


Figure 2.- U.S. energy demand for different modes of transportation (Lewis projection, March 1974).

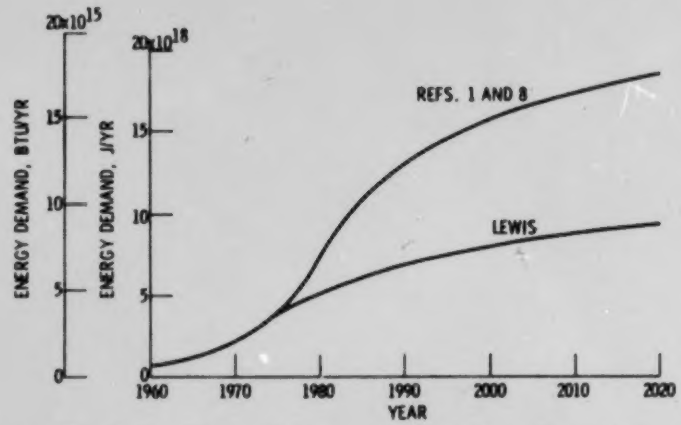


Figure 3.- U.S. aircraft energy demand projections.

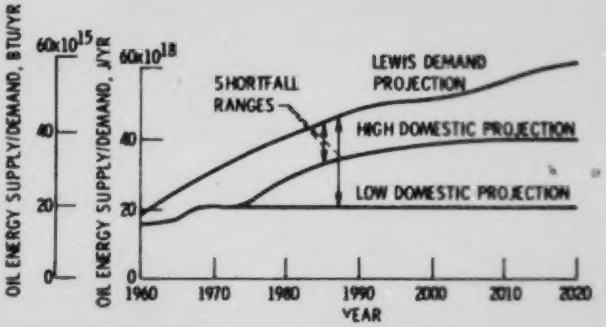


Figure 4.- U.S. annual oil supply/demand projection.

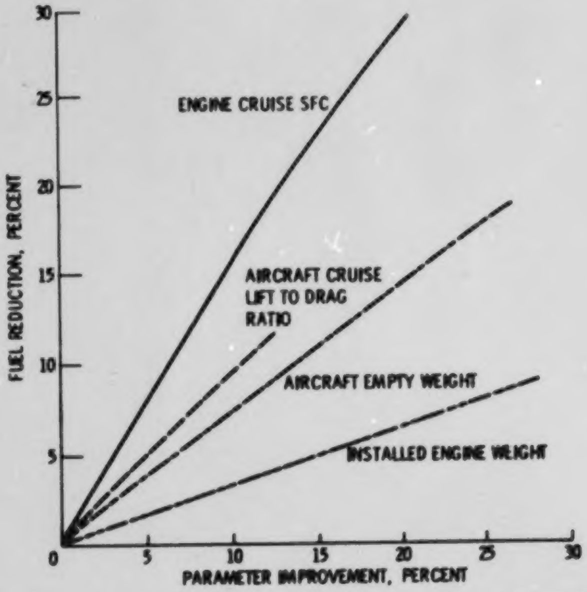


Figure 5.- Fuel consumption sensitivity for aircraft-engine parameters; DC-10 class "rubber airplane" on a 5560-kilometer (3000-n.mi.) mission.

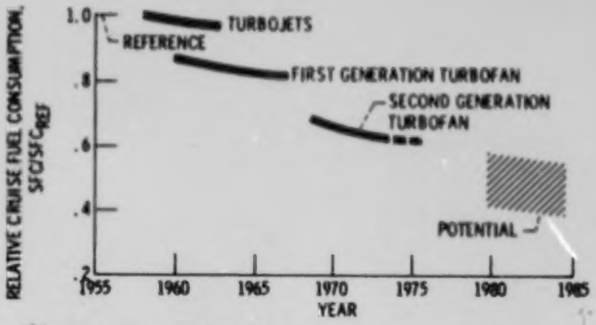
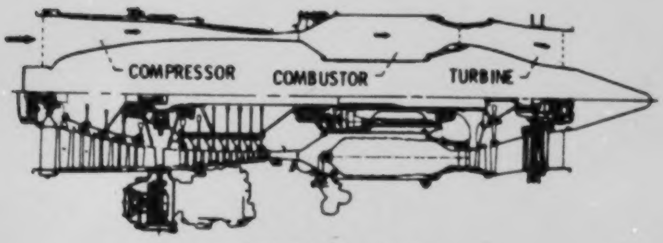
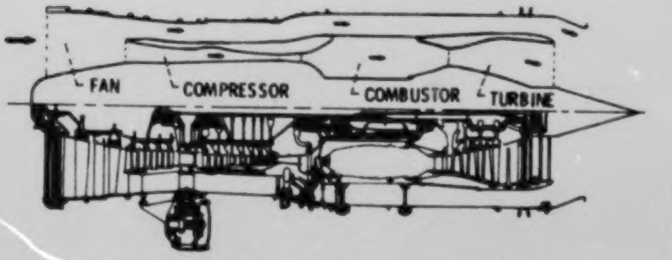


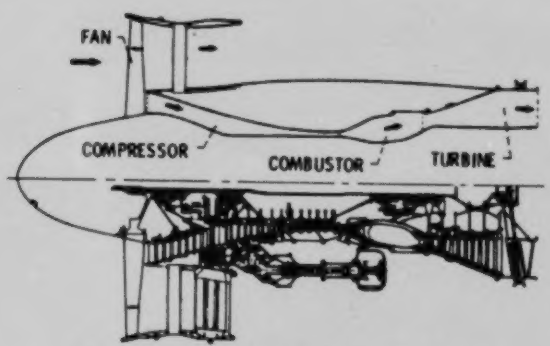
Figure 6.- Relative fuel consumption of commercial aircraft jet engines.


COMPRESSOR
COMBUSTOR
TURBINE

(a) Turbojet.


FAN
COMPRESSOR
COMBUSTOR
TURBINE

(b) First generation turbofan.


FAN
COMPRESSOR
COMBUSTOR
TURBINE

(c) Second generation turbofan.

Figure 7.- Current commercial jet aircraft engines.

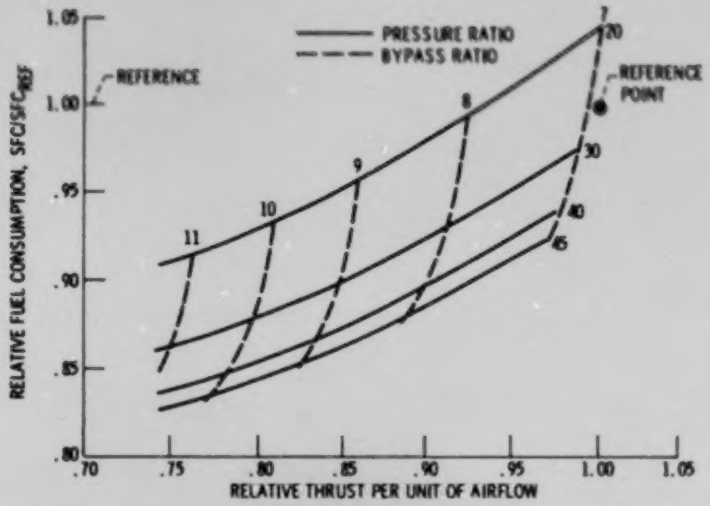


Figure 8.- Projected turbofan engine performance potential for reducing fuel consumption of fugure propulsion systems.

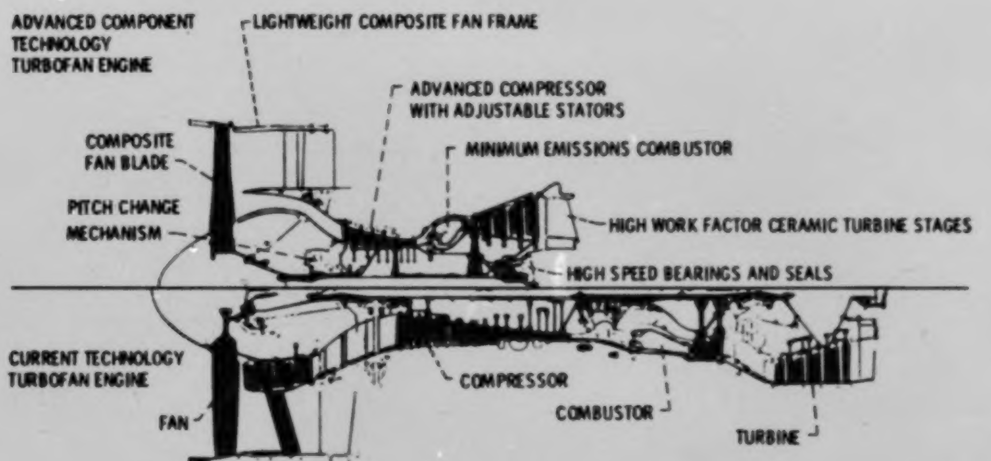
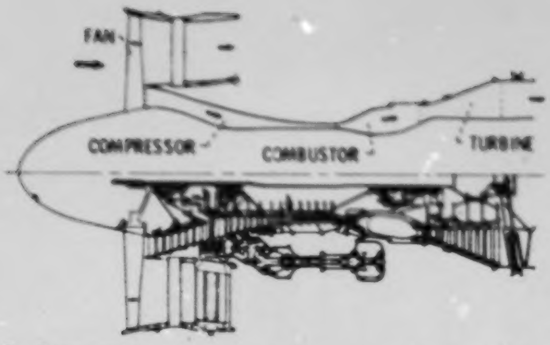
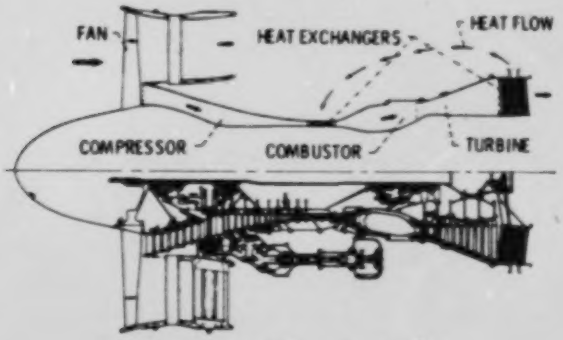

ADVANCED COMPONENT TECHNOLOGY TURBOFAN ENGINE
LIGHTWEIGHT COMPOSITE FAN FRAME
ADVANCED COMPRESSOR WITH ADJUSTABLE STATORS
MINIMUM EMISSIONS COMBUSTOR
COMPOSITE FAN BLADE
PITCH CHANGE MECHANISM
HIGH WORK FACTOR CERAMIC TURBINE STAGES
HIGH SPEED BEARINGS AND SEALS
CURRENT TECHNOLOGY TURBOFAN ENGINE
COMPRESSOR
COMBUSTOR
TURBINE
FAN

Figure 9.- Advanced technology needs for future low fuel consumption turbofan engines.


FAN
COMPRESSOR
COMBUSTOR
TURBINE

(a) Conventional second generation turbofan.


FAN
HEAT EXCHANGERS
HEAT FLOW
COMPRESSOR
COMBUSTOR
TURBINE

(b) Regenerative turbofan.

Figure 10.- Comparison of turbofan engine cycles.

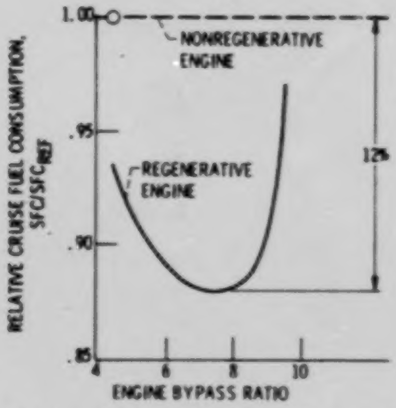
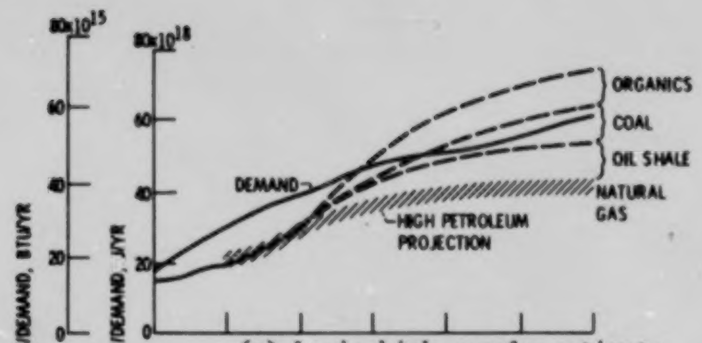
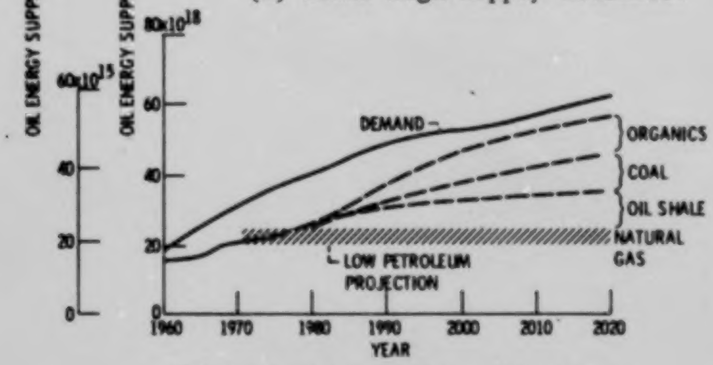


Figure 11.- Potential reduction in cruise specific fuel consumption from using regenerative turbofan engine. Turbine inlet temperature, 1810 K (2800° F).

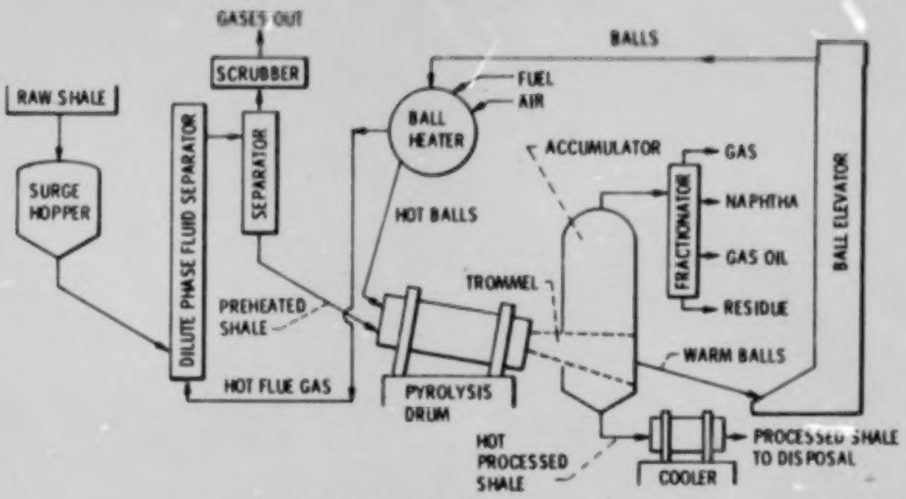


(a) Lewis high supply estimate.

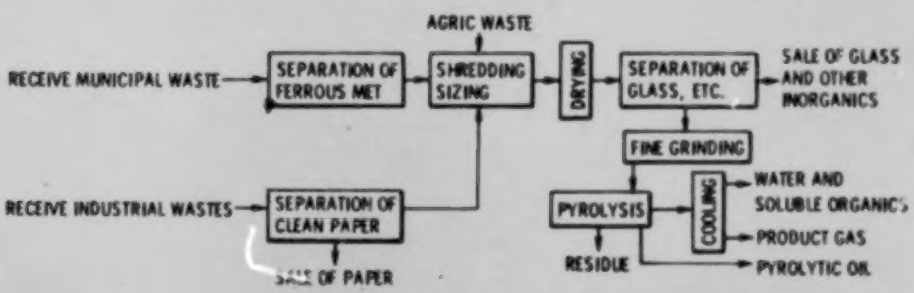


(b) Lewis low supply estimate.

Figure 12.- Annual oil supply/demand projection. Investment in syn-crude development, 1 x 10^9 dollars/year/syn-crude.


GASES OUT
SCRUBBER
BALLS
RAW SHALE
FUEL
AIR
BALL HEATER
SURGE HOPPER
DILUTE PHASE FLUID SEPARATOR
SEPARATOR
ACCUMULATOR
GAS
FRACTIONATOR
NAPHTHA
BALL ELEVATOR
HOT BALLS
GAS OIL
TROMMEL
RESIDUE
PREHEATED SHALE
WARM BALLS
HOT FLUE GAS
PYROLYSIS DRUM
HOT PROCESSED SHALE
PROCESSED SHALE TO DISPOSAL
COOLER

(a) Oil shale retorting processes.


AGRIC WASTE
RECEIVE MUNICIPAL WASTE
SEPARATION OF FERROUS MET
SHREDDING SIZING
DRYING
SEPARATION OF GLASS, ETC.
SALE OF GLASS AND OTHER INORGANICS
FINE GRINDING
WATER AND SOLUBLE ORGANICS
RECEIVE INDUSTRIAL WASTES
SEPARATION OF CLEAN PAPER
PYROLYSIS
COOLING
PRODUCT GAS
SALE OF PAPER
RESIDUE
PYROLYTIC OIL

(b) Converting waste products to fuel.

Figure 13.- Syn-crude oil processing methods.

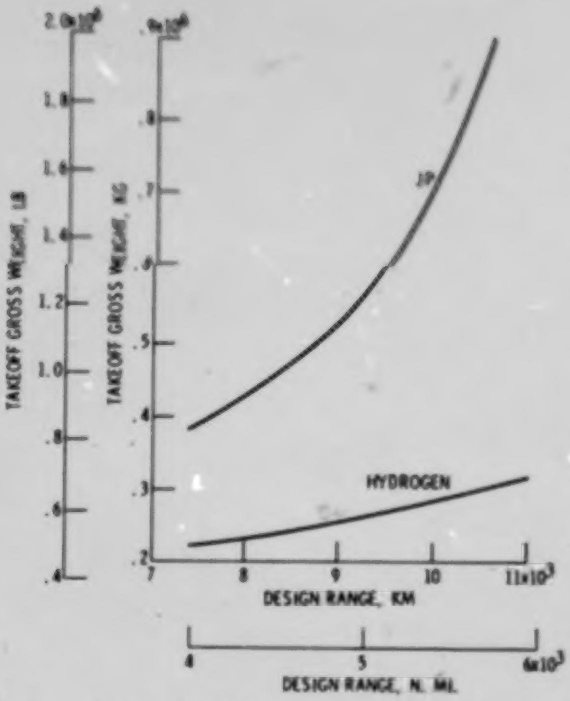


Figure 14.- Aircraft gross weight comparison for hydrogen and JP fuels.

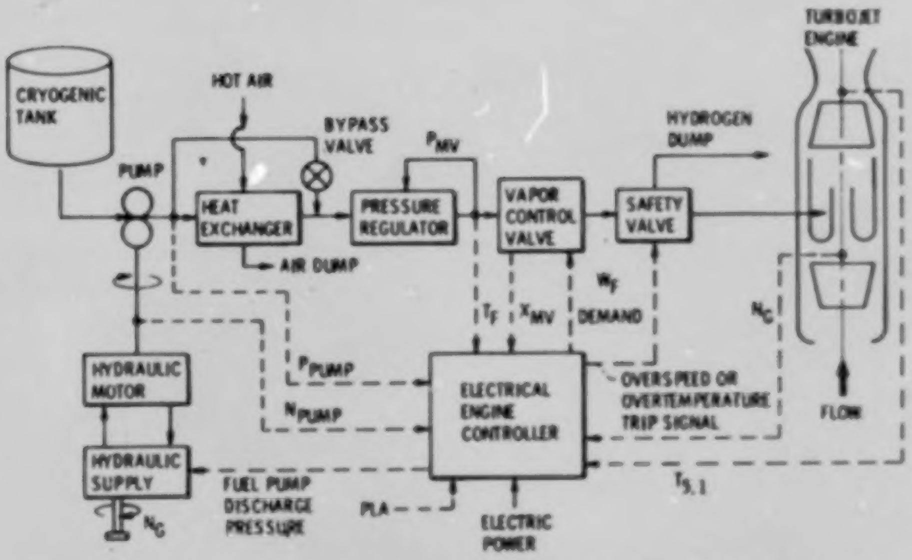

TURBOJET ENGINE
CRYOGENIC TANK
HOT AIR
BYPASS VALVE
P_MV
HYDROGEN DUMP
PUMP
HEAT EXCHANGER
PRESSURE REGULATOR
VAPOR CONTROL VALVE
SAFETY VALVE
AIR DUMP
W_F
T_F
X_MV
DEMAND
N_G
P_PUMP
HYDRAULIC MOTOR
ELECTRICAL ENGINE CONTROLLER
OVERSPEED OR OVERTEMPERATURE TRIP SIGNAL
N_PUMP
FLOW
HYDRAULIC SUPPLY
T_5.1
FUEL PUMP DISCHARGE PRESSURE
N_G
PLA
ELECTRIC POWER

Figure 15.- Prototype hydrogen fuel system for aircraft engine.

COMPUTATIONAL AERODYNAMICS

By Dean R. Chapman
NASA Ames Research Center

Over the past four decades the amount of wind tunnel testing required to develop new aircraft has increased markedly. If these past trends continue into the decade of the 1980's, over ten years of accumulated wind tunnel test time and costs of approximately 100 million dollars will be required for each new major aircraft. Computer capability has followed an opposite trend over the past twenty years: the cost for a computer to simulate a given flow field has decreased a factor of 10 approximately every five years. Although this latter trend has existed for some time, it is still not possible for even the most advanced current computer, the ILLIAC IV, to solve the full governing differential equations of fluid motion, the Navier-Stokes equations, for configurations as complex as aircraft. For this reason, as computer capabilities have improved, progressively improved stages of approximation to the Navier-Stokes equations have been used. This process is expected to continue until computer capability improves sufficiently to solve in detail the Navier-Stokes equations in a practical amount of time and at a practical cost.

A stage of approximation currently under exploration uses the time-averaged Navier-Stokes equations: no terms in the full equations of motion are neglected, but certain terms that involve turbulent momentum and heat transport are modeled. This approximation is limited mainly by the accuracy of the turbulence model. Some examples for two-dimensional flows are presented. The computational time for this stage of approximation is such that only advanced computers such as the ILLIAC are practical for such simulations.

A stage of approximation of the future would involve solving the complete time-dependent Navier-Stokes equations of viscous flow motion, computing all the significant turbulent eddies in a given flow. The pacing item for achieving such simulations is the development of an advanced computer, since even the ILLIAC cannot handle in a practical way anything but extremely simple flows within the framework of the full time-dependent equations of viscous fluid flow. Once such a stage is reached wherein the full Navier-Stokes equations can be readily solved by a computer, the relative roles of wind tunnels and computers in providing flow simulations should change markedly.

The expectation that advanced computers may eventually displace experimental facilities as the principal means of providing dynamic simulations is neither new nor foreign to past experience. Two important examples in computational mechanics are noted wherein this displacement has already occurred: in trajectory mechanics and in neutron transport mechanics. Fluid mechanics may be a field in which such a displacement again occurs.

SOME TRENDS IN AIRCRAFT DESIGN - STRUCTURES

By George W. Brooks
NASA Langley Research Center

SUMMARY

The objective of this paper is to highlight some of the trends and programs currently underway on the national scene to improve the structural interface in the aircraft design process. The National Aeronautics and Space Administration shares a partnership with the educational and industrial community in the development of the tools, the criteria, and the data base essential to produce high-performance and cost-effective vehicles. The paper discusses several thrusts to build the technology in materials, structural concepts, analytical programs, and integrated design procedures essential for performing the trade-offs required to fashion competitive vehicles. The application of advanced fibrous composites, improved methods for structural analysis, and continued attention to important peripheral problems of aeroelastic and thermal stability are among the topics discussed. The paper notes some areas where the multidisciplinary environment of the University is believed to be uniquely suited to enhancing the development of improved aircraft.

INTRODUCTION

Most of us have probably been amused at some time in our careers at the cartoons which depict the absurd configurations for airplanes (ref. 1), which reflect the unique desires of the aerodynamicist, the structural designer, or the propulsion expert. Such humorous reflections serve to remind us that the design of an effective aircraft is a detailed and complex trade-off of many variables - it ain't easy. In any arena, whether it be military defense or commercial transportation, the winning aircraft are those which prove most effective within a given set of constraints. The measure of effectiveness is highly mission oriented, but for the commercial transport it boils down to a simple criteria - will this aircraft, in competition with others having similar capabilities, provide the best profit margin throughout its life expectancy of 20 or more years.

The central question then is: How do you define and design the most effective aircraft? It is not likely that any answer to this question, whether it be simple or complex, could stand a test of uniqueness. But the search for the optimum provides a good focus for the selection and development of advanced technologies.

Despite the complexity of the aircraft design process, the goals for cost-effective structural design can be summarized fairly concisely as shown in figure 1. Simply stated, we seek ways to integrate the aircraft subsystems quickly and efficiently and to build the aircraft with lightweight materials which are economical, tough, and easy to fabricate. To attain these goals, the ingenuity of the aircraft designer is tested by the need to effectively incorporate new technologies which broaden mission capabilities. A fairly recent study on vehicle technology for civil aviation (refs. 2 and 3) provides a good summary of numerous options. But the designer must also look at the aircraft as a total system because the margins between productive and unproductive aircraft grow exceedingly small in the highly competitive environment of the world marketplace, and the advantages of any technology area taken as an entity may be inconclusive or erroneous. In response to the growing need to assess the relative merits of contending options for technology development and application, several systems studies have been performed which reflect the manufacturers' (refs. 4 to 9) and users' viewpoints (refs. 10 and 11). Other recent systems studies have examined such related topics as terminal area compatibility (refs. 12 and 13), economic forecasts and impact (refs. 14 and 15), specific studies of structural options (refs. 16 and 17), and fuel conservation trade-offs for future aircraft (ref. 18).

The true impact of all these efforts must await tests in the crucible of operational experience. But some expected trends persist. Relative to structural design, structural weight reductions accrue a double benefit - lower costs for operations and reduced demands for depleting fuel supplies as reflected in figure 2. The effectiveness of the design process can be improved by providing analysis and design programs which speed up the cycle and provide better visibility for critical decisions. The purpose of this paper is to relate some of the efforts currently underway relative to these and other aspects of design of aircraft structures, and to highlight representative NASA research programs and results.

The content of this paper represents the ideas and efforts of many of the writer's associates, both inside and outside NASA, who strongly believe in the future of aeronautics. Their continued efforts to develop new materials and structural concepts, and new tools and methodology to assemble them in more cost-effective and durable aircraft, are inspiring. It is the writer's hope that the paper properly projects some of their ideas and helps, in some small way, to gain continued support for their research. The writer is particularly indebted to those associates who helped to assemble the material in this paper.

DEVELOPMENT OF TOOLS FOR AUTOMATED INTEGRATED STRUCTURAL ANALYSIS AND DESIGN

The design of cost-effective, high-performance aircraft structures necessitates continual improvements in the total development process, beginning with conceptual design and continuing through model variations to incorporate new technology in the production series. Each step in the process must be supported by the best analytical methods available and the effective utilization of high-speed digital computers. These methods have generally evolved as computer programs which are written to solve a broad spectrum of problems ranging from the analyses of simple structural components (refs. 19 to 21) to the interactive-integrated design of complete aircraft (refs. 22 to 26). The major objective in the development of these tools is to maximize the "work function" of the structure (no excess materials), minimize the time span of the design function (lead the competition to the marketplace), and optimize the utilization of high-cost manpower in the decision process.

Special-Purpose Automated Analysis and Design Programs

Special-purpose programs are often developed to improve a capability or as tools to do research on new or advanced concepts in an area. These programs are often tailored toward a special class of structures or some special class of problems associated with these structures (ref. 20). Two examples of classes of special-purpose programs are those that improve the capability for performing thin-shell buckling analyses and those developed to carry out research in the minimum-mass design of wings subject to multiple design constraints such as flutter, strength, and minimum gage.

STAGS (refs. 27 and 28), BOSOR (ref. 29), and SRA (refs. 30 and 31), are examples of programs that have improved analytical capabilities for shells such as aircraft fuselages. They are sophisticated programs applicable to the nonlinear collapse loads of complex branched or segmented shells, as well as to linear bifurcation buckling loads due to thermal and mechanical applied loads. BOSOR and SRA are one-dimensional shell-of-revolution programs that are applicable to the vibrational characteristics of these shells. BOSOR has a plastic analysis capability, and SRA can be used to determine the imperfection sensitivity of a shell of revolution. STAGS is a two-dimensional general asymmetric-shell program that also has some capabilities for transient response and piecewise linear plastic analysis. STAGS and BOSOR use the finite-difference method to solve the shell problem, based on an energy formulation of the nonlinear shell equations. SRA is based on the field method which transforms the two-point boundary-value problem associated with the governing shell equations into a first-order initial-value problem which is solved by numerical integration. Advantages of this method are that it is free of numerical ill-conditioning problems and solution convergence is not a problem. Programs of these types allow problems to be solved that were impossible as recently as a decade ago. For example, STAGS has been used (ref. 32) to solve such nonlinear asymmetric problems as the buckling of shells with cutouts (fig. 3). STAGS has also been used (ref. 33) to improve the interaction curves for the collapse of cylindrical shells under bending and pressure loads by taking into account geometric nonlinear effects (fig. 4), and STAGS has been used successfully to analyze a shell buckling problem with 20 910 degrees of freedom (ref. 34). Vibration analysis and hybrid (finite difference/finite element) analysis capabilities are currently being developed for STAGS.

SWIFT (ref. 35), WIDOWAC (ref. 36 and 37), and TSO (ref. 38) are examples of programs that were developed as research tools to study the minimum-mass design of wings subject to multiple design constraints (such as flutter, strength, and minimum gage) and to study some of the problems of interdisciplinary design (structures and aerodynamics, in this case). These programs are based on the sequential unconstrained minimization technique in which the design constraints are introduced by means of an interior penalty function.

SWIFT was developed for platelike wings. The governing plate equations are solved by assuming a parabolic approximation to the wing deflection in the chordwise direction, and finite differences are used to approximate spanwise derivatives. Second-order piston theory is used for supersonic unsteady aerodynamics. By using these idealizations, it was possible to show that minimum-mass designs that satisfy combined design constraints of flutter and strength are substantially different from designs that satisfy strength requirements alone and flutter requirements alone (fig. 5).

In WIDOWAC, a wing structure is modeled by a finite-element representation in which second-order piston-theory unsteady aerodynamics are used for supersonic conditions and kernel-function aerodynamics are used for subsonic conditions. Newton's method with approximate second derivatives (ref. 36) is the optimization algorithm used for each unconstrained minimization. Several flutter constraints can be considered simultaneously along with strength and minimum-gage constraints. Additional constraints are being added to WIDOWAC, such as a deflection constraint and a continuous flutter constraint that will prevent design problems from occurring due to a hump-mode flutter condition. Composite material and static aeroelastic capabilities are also being developed.

TSO is used to provide minimum-mass design of trapezoidal wing boxes for subsonic flight conditions. A Rayleigh-Ritz plate analysis procedure is used for the structural representation, and doublet-lattice unsteady and Woodward-Carmichael steady aerodynamics are used. Both metal and composite materials can be optimized. For composite materials, TSO determines the optimum ply orientation and laminate thickness to take maximum advantage of anisotropic tailoring of the wing. The strength constraint is based on static aeroelastic loads which are recomputed as the design variables are changed and thus account for changes in flexibility on the loads.

Special-purpose programs can be used in conjunction with general-purpose programs like ATLAS by providing analytical design data in place of empirical or statistical data, thereby upgrading the general-purpose program.

Many of these special-purpose research tools become so successful that they grow into production tools.

Improved Fully-Stressed Design Procedures

Another area of interest relative to minimization of structural weight to maximize performance is fully-stressed design (FSD). FSD procedures are typically used to size structures under mechanical loads and subject to constraints on allowable stress and minimum gage of the structural elements. Because the thermal stress in a structural member is insensitive to member size, the usual FSD procedure has two principal shortcomings with regard to thermal structures: (a) if the thermal stress is a significant fraction of the total stress in a member, the FSD algorithm will perform needless resizing steps in often futile attempts to drive the total stresses to the allowable values and (b) if sufficiently high thermal stresses are induced in the structure, the ordinary FSD procedure will simply diverge.

An improved version of fully-stressed design for heated structures has been developed for the purpose of avoiding the shortcomings previously cited. The new procedure known as Thermal Fully-Stressed Design (TFSD) is based on the resizing formula shown in figure 6. Also shown is the usual FSD resizing equation. The quantity λ (without a subscript) is the ratio of total stress in a member to its allowable stress, whereas λ_m and λ_t represent the corresponding ratios due to purely mechanical and thermal loads, respectively. The new procedure resizes so as to drive the mechanical stress to the maximum permissible value and does not waste iterations attempting to alter the thermal stress. For cases where the structural temperatures as so large that no design exists, the algorithm is coded to calculate the maximum fraction β of the applied temperatures which can be accommodated.

To illustrate the new algorithm, the results of a sample calculation are shown in figure 6. The configuration is a truss structure which resembles a hypersonic wing. The structure is modeled by bar elements and has 136 design variables. Loads consist of a three-dimensional temperature distribution and a uniform air load plus an applied couple simulating elevon loads. Results are presented in the form of plots of mass as a function of number of iterations for ordinary FSD (dashed line) and for the new thermal FSD (solid line). Both methods gave essentially the same total mass, but the thermal FSD required only 11 iterations to converge within 1 percent of the final weight whereas the FSD required 47 iterations for the same degree of convergence. The results of this problem suggest the efficiency of the improved FSD algorithm for problems involving significant thermal loading of structures.

General-Purpose Automated Analyses

By general-purpose automated analyses, we refer to procedures based on the finite-element method which have the capacity and variety of elements for performing structural analyses of a complete vehicle. Several such programs exist in the aerospace community, but our comments will be limited to three such programs which have received support from NASA in their development - NASTRAN, ATLAS, and SPAR.

A commonality of most general-purpose finite-element programs is the capability to perform static-stress analyses and determine natural vibration characteristics of finite-element structural representations containing a large number of elements and degrees of freedom. Additional analytical capabilities, differences in system design, and user convenience features included in NASTRAN, ATLAS, and SPAR will be discussed.

NASTRAN (refs. 39 and 40) contains specific sequences of analytical computations called rigid formats which can be selected by the user to perform linear stress analysis, limited nonlinear stress analysis, buckling analysis, vibration analysis, transient response, frequency and random response, extraction of complex eigenvalues, linear and nonlinear steady-state heat transfer, and linear transient heat transfer. These rigid formats allow use of the program by structural analysts who have limited computer programing background. In addition, a Direct Matrix Abstraction Program (DMAP) language is available to allow a more sophisticated user to develop a particular sequence of computations. The current version of NASTRAN, Level 15.5, contains approximately 200,000 source statements and is operational on IBM, CDC, and UNIVAC computers. Figure 7 shows the detail and one of the modes of a finite-element model of an advanced supersonic technology vehicle generated by use of NASTRAN. Planned improvements for Level 16 include an element resizing procedure, complete heat transfer (conduction, convection, and radiation), automated substructuring, some additional and some improved finite elements, and several system modifications to improve computational efficiency (fig. 8). Although initially developed for analysis of space vehicle structures, NASTRAN is used (refs. 41 to 43) for analysis of all types of structures at more than 240 installations, most of them outside the aerospace industry.

ATLAS (ref. 44) is an integrated system of computer programs (fig. 9) developed for structural/aeroelastic design of advanced aircraft configurations with initial emphasis on supersonic transport configurations with low-aspect-ratio wings. The existing ATLAS program, for which the initial development was sponsored entirely by The Boeing Company, is being extended under government contract and delivered to the NASA Langley Research Center. This program will provide an integrated aeroelastic analysis/design capability for design studies of advanced aircraft configurations and will serve as a "test bed" for research on a large integrated structural analysis/design system. Because of the Boeing proprietary interests in the program, general use of ATLAS is restricted to government-related projects until February 1978. The program is intended to integrate all related structural disciplines to a common framework. Capabilities presently included are the control module used to make analysis path decisions and monitor execution, data management system for communication of data between modules through named random access disk files, and technical modules in areas of static analysis including substructuring, mass calculations, vibration analysis, steady and unsteady aerodynamics, flutter analysis, fully stressed resizing, and plotting. Capabilities to be added to ATLAS are additional features for automatic generation of input data such as winglike and bodylike geometry, fuel and payload distributions, thermal stress, residual flexibility to include the stiffness contribution of higher modes in a modal vibration analysis, implementation of ATLAS on interactive graphics equipment, improved structural resizing and interfaces to NASTRAN and FLEXSTAB, and a program for calculating aeroelastic loads. In addition to its comprehensive array of technical capabilities from structural-related disciplines, ATLAS contains many user convenience features intended specifically to expedite the analysis/design process for aircraft structures. Future additions include a module to resize the structure to satisfy stiffness or flutter requirements. Existing ATLAS has been applied to several analysis tasks. Figure 10 shows that the time and resources required by ATLAS for structural analysis of a supersonic commercial transport at the preliminary design level were approximately half that required by conventional methods. Planned additions to ATLAS should provide greater savings. The existing ATLAS program relies heavily on a 60-bit word and, hence, is operational only on CDC computers.

The trend in the development of large, general-purpose automated analysis programs has been to develop a basic system and then extend it with more and more technical capability. The basis of this new technical capability is usually tested and verified in special-purpose programs before integration into a large system. With this large stable of technical capability developed, an emerging trend is to design computer systems which make this capability much more useful to structural analysts. Most large programs are developed in a modular (a specific technical capability is associated with a certain group of subroutines) fashion so that the modules can be improved or replaced within a given program. An aspect of the design of such systems, that is receiving increased attention, is the desirability of exchanging or sharing modules between large programs. Also, the tailoring of these modules for computational efficiency and minimum core storage requirements is important to reduce the impact on computer facilities. Attention to such factors in general-purpose analysis programs will allow easier modification for specific tasks and enable the analyst to make use of advances in computer technology such as time-share, minicomputers, low-cost interactive graphics, and various features of large fourth-generation computers. Development of user convenience features, such as preprocessors for automatic generation of input data and postprocessors for graphic display of numerical results, are being developed to greatly reduce this time-consuming aspect of using general-purpose analysis systems.

The SPAR system (ref. 45) is an outgrowth of the SNAP program. It is distinguished by being designed specifically to have a low impact on the computing system by minimal use of core and efficient use of random access data storage. The system is composed of a group of stand-alone programs (provide specific technical capability) which exchange information with a data base to allow unlimited revision of content by the user. The separate programs or processors can be used in any logical sequence to perform a desired analysis task. Re-entrant operation, as required for redesign, nonlinear analysis, parametric studies, and so forth, is also easily accommodated. Basic technical capabilities presently include linear stress analysis, bifurcation buckling, and vibration analysis with the option to include prestress in buckling and vibrational characteristics. SPAR is operational on UNIVAC and CDC computers and can be operated interactively on the UNIVAC system. Low core storage requirements could allow implementation of SPAR on minicomputers.

Integrated-Interactive Structural Design

As described in the previous sections, much progress continues to be made in the development of special-purpose and general-purpose computer programs for analysis and design trade-offs for aircraft structural components and systems. A few years ago it became clear that a need exists to effectively use the high-speed third- and fourth-generation digital computer to integrate and automate the total design process in such a way as to maximize the effectiveness of the aerodynamic, structural, and propulsive systems in the design of an optimal aircraft for a given set of requirements. The goal is depicted by figure 11. One assessment of the potential for improvements by automating the aircraft design process is given by figure 12 which shows the extent to which various modules for automated preliminary design exist, are needed, or probably cannot be automated with current technology.

In view of the potential benefits, NASA conducted two feasibility studies (refs. 46 to 59) of Integrated Programs for Aerospace Vehicle Design (IPAD). Figure 13 shows a schematic of the IPAD system and figure 14 characterizes the role of IPAD in product development. The aerospace industry was most cooperative in these studies and provided NASA its critique on numerous occasions. The general concensus of the studies was that the technology exists to assemble IPAD in such a way as to benefit the industry (fig. 15) but that substantial care should be exercised in the design of IPAD so that existing design organizations can implement it in an evolutionary way (fig. 16). As a consequence of the favorable findings of the feasibility studies and evaluations by potential users, NASA is proceeding with the development of the IPAD System according to the plan shown in figure 17.

General Comment on Computer Programs

Before leaving the subject of the role of the computer and computer programs in aircraft structural design, it seems appropriate to emphasize that these tools are the result of, and an aid to, the thinking, decision, and management processes - not substitutes. They cannot supplant the need for fundamental research into the physical consequences of the coupling of materials, structures, and loads and cannot predict a structural reaction beyond the capabilities provided by the programed physical relationships or equations. The available and projected tools are powerful aids to productivity when properly used, but the new dimension in capability requires a broader spectrum of knowledge on the part of the user. In a nutshell, the design engineer must be able to anticipate the requirements of the program and the nature of the results on the basis of physical reasoning and experience - otherwise he can become the victim of a costly numbers game. He can get good results faster and cheaper only if he can effectively use sophisticated computer programs as computational aids to supplement logic.

The University is in a unique position, and bears a substantial responsibility, in the training of scientists and engineers in the relative roles and significance of the computer. The programing of a high-speed computer to generate solutions to difficult structural problems holds great fascination for many engineers, and it is not unexpected that many may become so enthralled with the solution process that they forget the significance of the answer. In the age of specialization there is both a need and a place for the individual to program complex systems and assess the reactions. But there is a greater need for the generalist who can look at the total problem, define the bounds and constraints of the system, decide the relative roles of analysis and experiment, and organize the appropriate mix of human and physical resources to arrive at an "acceptable" answer. Such individuals may not be able to program the buckling of an aircraft fuselage on a computer, but it is essential that they know it might buckle and that a good computer program might tell them how to strengthen it in a fraction of the time and at a lower cost than would be incurred otherwise.

THE EMERGING ROLE OF ADVANCED COMPOSITES

Background and Status

Since about 1958, aeronautical engineers have recognized advanced composite materials as promising candidates for improving the performance of aircraft by increasing the efficiency of the structure. The blending of high-strength fibers such as graphite, boron, Kevlar 49, and glass into epoxy, polyimide, or metallic matrices to produce a tailored structure provides a new dimension for the creative structural designer. The major thrusts in this area were carried during the first decade by the Air Force Materials Laboratory under the direction of Dr. Alan Lovelace and Mr. George Peterson. In recent years, NASA and several elements of the Department of Defense have teamed with the aircraft industry and universities to push this new technology - and the momentum continues. Several national and international conferences (refs. 60 to 73) reflect the substantial progress being made in the development of these materials and their applications to a wide spectrum of structural elements. However, despite this notable progress in a relatively short time span, some critical problems still remain to be solved before these material systems gain general acceptance in aircraft design. The major problem is the uncertainty about the durability of these material systems. Since the time span of applications is only a few years, the data base is not adequate to assure that these materials will withstand the airline environment for a period of 15 or 20 years. Although there is no reason to doubt that they will, there is good reason to desire additional data and experience to demonstrate greater confidence.

A second problem is the relative inadequacy of the design tools and data base for using these anisotropic, inhomogeneous materials to maximum advantage. Considerable effort is now underway throughout the aerospace community to fulfill this need, but more data are needed.

The costs of composite materials have been reduced substantially during the past few years, but they will remain relatively high until the usage justifies increased production volumes. Even so, significant pieces of airframe structures are now being built with savings in both weight and cost relative to the metal counterparts by the use of innovative manufacturing tools and processes.

Design Technology for Advanced Composite Structures

A comprehensive national program is underway to establish a design technology for advanced composite structures comparable to that which presently exists for aluminum structures. Primary objectives of this program are to (1) understand failure phenomena, (2) develop a weight-strength data base for design, (3) determine the relative merits of various structural concepts, and (4) develop and evaluate appropriate analysis and design tools. We would like to illustrate this activity by examples of some of the work at the Langley Research Center on epoxy compression panels and shear webs.

Composite materials are inherently highly orthotropic and can be tailored to provide a wide range of elastic structural behavior. Although this provides the designer with degrees of design freedom not previously available with isotropic metal, it also complicates the design process with additional design variables. To effectively handle the design of highly tailored composite structural components, a computer program (ref. 74) is being developed at Langley which uses mathematical programing techniques to automate the design process. Figure 18 shows a simplified flow diagram. The user selects a generic geometry, loads to be applied, and materials to be considered. The "parameter optimizer" then increments the design variables such as the number of layers, the filament orientation, and stiffener dimensions in accordance with the optimization scheme and constraints. The process is iterated until a least-weight design is achieved.

This computer program has been used to design graphite/epoxy hat-stiffened compression panels over a wide range of loadings. A summary of some of the results is shown in figure 19, which is a standard weight-strength plot of the strength parameter N_x/L and the weight parameter W/bL^2. Results from the computer program for the composite panels are shown as a solid line and the hatched area represents data from previous NACA experimental programs (refs. 75 and 76). The results shown that the composite panels are half as heavy as the best available aluminum panels. An experimental program is presently being conducted to determine the validity of the theoretical predictions, and some early results are shown as circles on the curve. These results are all from crippling specimens such as shown in a failed condition in figure 20. Typically the experimental results are within 15 to 20 percent of the theoretical predictions. In the near future this curve will be further validated by tests of 1.5-m- (5-ft-) long by 0.6-m- (2-ft-) wide compression panels.

A study of the weight-strength characteristics of graphite/epoxy shear webs is also being conducted and some preliminary results are shown in figure 21. The theoretical predictions for graphite/epoxy sandwich shear webs are shown as the solid line and the hatched area represents previous NACA experimental data on aluminum (refs. 77 and 78). In the heavily loaded range ($N_{xy}/b > 10^5$), weight savings of 50 percent are predicted for the composite shear webs over the aluminum webs with some reductions in weight savings for the lower loadings. The apparent reason for this decrease in weight savings at lower loadings is that the lower portion of the aluminum data corresponds to tension-field designed webs which buckle at a small percentage of limit load. If such webs are precluded, as is necessary in modern stiffness-critical aircraft, the composite shear webs will show weight savings of about 50 percent over the entire loading range. The circle in the figure is the result of a recent test of the large shear web (91.4 cm (36 in.) by 101.6 cm (40 in.)) shown in figure 22. The left-hand side of the test specimen is a dummy aluminum web for loading purposes and the right-hand side is a ±45° graphite/epoxy web with an aluminum honeycomb core 1.52 cm (0.6 in.) deep. The specimen is loaded as shown in the insert. This short beam loading technique results in a predominantly shear loading on the web. The first web tested failed at 80 percent of the predicted load and highlights the need for improvements in strength and stress prediction techniques for orthotropic materials. As a result of this test, we have been able to pinpoint some of the deficiencies in the modeling procedure which promised improved analytical accuracy.

Chopped-Fiber Molded Structures

The versatility of high-strength fibers also offers considerable promise for cost-effective design of strong, lightweight chopped-fiber moldings. Two examples are discussed as illustrations of this technology.

Figure 23 compares helicopter tail-rotor shaft couplings made of aluminum, and moldings of chopped fibers (graphite, glass, and Kevlar 49) in epoxy resins. The couplings were bonded to test fixtures and loaded in torsion to failure. It is of interest to compare the relative weights, strength, and costs of the components.

The second application involves the use of chopped and unidirectional graphite and Kevlar 49 fibers in the fabrication of the front spar and hinge assembly for the all-composite spoiler being developed for flight service on the Boeing 737 airplane. Graphite/epoxy and Kevlar 49/epoxy were molded into individual subassemblies and then incorporated into five basic assemblies in successive molding operations as shown by figure 24. These composite spoilers will undergo FAA certification for installation on Boeing 737 airplanes in normal airline use.

Polyimides for Higher Temperature Composites

The general applicability of epoxy resins for structural composites applications is limited to the same temperature range as aluminum (i.e., 150° to 175° C). However, polyimide resins show considerable promise for extending the useful temperature range upward to about 315° C and consequently could substantially reduce the structural weights of supersonic aircraft and shuttle vehicles. Several types of polyimides (see refs. 73 and 79) are currently available and are being examined for their potential role in advanced structures. Examples of current polyimide materials are given in figure 25. Included are the producers, the type of resin (whether thermoplastic or thermosetting), curing temperatures, curing pressures, and postcure conditions. The "Remarks" column gives the significant characteristics of each resin and indicates that release of volatiles, short shelf life, low flow, brittleness, and lack of experience are some of the problems facing potential users of polyimides.

A major drawback to the application of polyimides is the relative difficulty of processing these materials, which requires large autoclaves having pressures and temperatures of up to 7 MN/m^2 (1000 psi) and 370° C, respectively. Therefore, emphasis is being focused on methods to ease fabrication complexity and reduce costs.

A novel method (fig. 26) has been developed for compaction and forming polyimide composites that uses thermal expansion of a silicone rubber pad to apply required pressures. This method eliminates the need for costly matched die molds and also eliminates thermal expansion problems associated with such molds. The silicone-rubber-pad method has been used to fabricate a lower contoured pan for the YF-12 wing panel shown in figure 27. The upper and lower surfaces of HTS graphite/P13N polyimide are bonded to fiberglass/polyimide honeycomb core by using an addition reaction polyimide adhesive developed at Langley Research Center. The fabrication methods look promising. The panel weighs less than 50 percent of the YF-12 production panel which is stiffener stabilized titanium.

Longtime Exposure Effects on Polyimide Composites

The performance of polyimides under longtime exposure (ref. 80) must be established to determine their suitability for use in structural applications such as supersonic vehicles. Some research results obtained at the Langley Research Center are shown by figure 28. The upper curve indicates the relative insensitivity of glass/polyimide composites to outdoor exposure for times in excess of 50 000 hours. This information represents the longest-exposure data available to date on polyimides. The other curves shown indicate the change in shear strength produced by exposure at 230° C followed by testing at either room temperature (upper curve) or 230° C (lower curve) for times exceeding 20 000 hours.

Results for exposure of graphite/polyimides at 370° C for various times at pressures ranging from sea level to near space conditions (1×10^{-6} torr) are also shown in figure 29. The degradation that occurs is the result of an oxidation mechanism. Note that 370° C exposure of the graphite/polyimide for 100 hours at 1×10^{-6} torr produced a very small change in room-temperature shear strength.

Boron/Aluminum Metal-Matrix Fabrication Research

Boron/aluminum metal-matrix composites are receiving considerable attention as possible candidate materials for supersonic aircraft structures. A significant NASA contractual program aimed at characterization of boron/aluminum (and polyimides) for 50 000-hour life at elevated temperatures is currently underway at General Dynamics/Convair. Langley is also conducting in-house research aimed at developing fabrication methods applicable to boron/aluminum composite components.

In one of the fabrication research studies on metal-matrix materials, a special brazing fixture was devised. This fixture makes use of a thin-metal preformed bladder to provide proper pressure in brazing a borsic/aluminum honeycomb-core sandwich panel as shown by figure 30. The borsic/aluminum honeycomb-core sandwich panel fabricated by this approach will be subjected to extensive ground tests and will also be flown on the YF-12 aircraft. Construction details for this panel as well as for the previously described graphite/polyimide panel are shown in figure 31.

Another boron/aluminum honeycomb-core sandwich panel is being fabricated for NASA by the McDonnell Douglas Aircraft Company. Extensive use of titanium interleaf material is made in conjunction with the boron/aluminum metal-matrix materials. This panel will also be subjected to ground tests and utilized in the YF-12 flight program.

Flight Service Evaluation of Composite Structural Components

For the past 10 years, numerous research programs have been conducted by the United States Government and industry to study the potential of advanced composite materials for use in aircraft structures. Although the structural advantages of composites are continuing to be demonstrated in the laboratory, widespread applications to commercial aircraft have not occurred. As previously mentioned, the high cost of composites and uncertainties relative to maintenance for long-life structural applications have been definite deterrents to their use. The aircraft manufacturers and the airlines must have confidence in composite materials before they commit themselves to the large-scale use of composites for commercial aircraft structural components, particularly for application to primary structures. The only way to really substantiate the integrity of composite materials is to investigate their behavior under typical service load and longtime environmental conditions.

Figure 32 shows the current and projected status of the NASA Langley Research Center sponsored programs aimed at flight service evaluation of composite materials in a variety of airframe structural component applications. (Programs emphasizing engine applications of composites are being conducted by NASA Lewis Research Center). Boron/epoxy, Kevlar 49/epoxy, graphite/polysulfone, and boron/aluminum composite materials are involved in the existing programs, the first of which began flight service in March 1972 and the most recent of which will begin flying about June 1975. Nine airlines and two military services are presently involved, and three more airlines are expected to become involved in the future. As the graph shows, a quarter of a million component flight hours were accumulated by July 1974. The indicated rapid accumulation of flight service time spread over five types of composite materials with 14 different user organizations will provide the data base needed to establish the confidence in long-term structural performance for secondary structures and should provide a realistic assessment of the composite reinforcement technique (CH-54B and C-130) for primary structures.

The results of several studies (refs. 4 to 18) have shown that the real payoff in the use of advanced composites will accrue from their application in primary structures. On the other hand, these structures are both expensive and flight critical, and their incorporation in transport aircraft requires confidence by both the user and the manufacturer who must produce competitive aircraft and guarantee their integrity. Overcoming this hurdle requires progressive participation by the aircraft manufacturer, the user airlines, and the certificating agency. The NASA is pursuing a program (fig. 33) to complete the cycle of composite applications by supporting the design, construction, and flight service of composite primary tail and wing structures for commercial transports. It is our hope that this program can be implemented and that the accrued confidence in composites applications will open up a new era in efficient aircraft structures.

NEW CONCEPTS FOR LIGHTWEIGHT METALLIC STRUCTURES

Because of their great promise for improving the structural effectiveness of future aircraft structures, advanced composites are receiving needed consideration as previously outlined in this paper. But it is clear that metallic structures will continue to dominate aircraft design for the foreseeable future, particularly for the higher temperature applications. Even with the extensive metallic experience that exists for conventional commercial and military aircraft, new concepts continue to evolve which are based on new materials, new fabrication techniques, and improved knowledge of various failure mechanisms such as fracture. For example, the U.S. Air Force has sponsored a series of studies (refs. 81 to 86) of advanced concepts for various vehicles aimed at a variety of missions.

The structures engineer is also faced with the challenge of developing new concepts for advanced aircraft that are exposed to new or more severe loading conditions and design constraints. Recent work at the Langley Research Center on metallic structures has been focused on concepts for advanced high-speed vehicles which would operate at supersonic and hypersonic speeds, and thus the work is heavily oriented toward concepts that can accommodate moderate to severe thermal environments. Many aerodynamic concepts for high-speed flight employ large low-aspect-ratio wings which tend to have large areas of lightly loaded, extremely flexible structure and, hence, are prone to aeroelastic problems. Obviously the thermal environment associated with high-speed flight is a significant driver in that material properties are degraded by high temperatures. Thermal stresses and fatigue must be accounted for, and passengers, fuel, and sensitive equipment must be protected from the heat load input to the structure. The trends in structures research to alleviate these problems are illustrated by examples of recent and current work at Langley directed toward supersonic and hypersonic cruise aircraft.

Structures for Supersonic Cruise Aircraft

Judicious use of advanced structural concepts is necessary to increase the payload fractions of future supersonic transports to make them commercially successful. Such transports will have unique structural problems due to the temperatures associated with supersonic flight and the large lifting surfaces required to maximize aerodynamic efficiency. At $M = 2.7$, external surfaces can reach temperatures in excess of 200°C, which necessitates the use of higher temperature low-density materials such as titanium.

In the arrow-wing planform, typical of projected efficient supersonic transport configurations, three different structural requirements occur in different areas of the wing as shown in figure 34. A large area in the forward wing box is lightly loaded and an efficient low-load-intensity structure must be used to preclude a large weight penalty due to the large area of structure involved. The aft wing box is heavily loaded but fairly deep, thus an efficient structural system that does not require closely spaced ribs or spars (which would be deep and hence heavy) is required. Finally, the wing tips are highly susceptible to aeroelastic instabilities, and a lightweight structure that is stiff in both bending and torsion is required.

Under contract to NASA, The Boeing Company and the Lockheed-California Company are developing efficient advanced structural concepts to meet these requirements. The studies are keyed to three broad technology readiness dates: near term, moderate term, and far term.

The near-term concepts are all metallic structures with the leading candidate for much of the wing box being aluminum-brazed titanium-honeycomb cover panels and corrugated spar and rib webs. This concept provides good inplane and normal bending stiffness and is efficient in compression. The concept has received substantial manufacturing development under a Department of Transportation SST follow-on program. The concept is also efficient in lightly loaded areas since a minimum-gage panel can span several feet between spars. Rear wing-box areas, heavily loaded in tension, would use stiffened plate construction because it is more efficient in tension and will support the smaller compressive and bending loads to which it is subjected.

The moderate-term concepts would still use titanium for the basic structure but would be reinforced with uniaxial high-temperature composite material such as boron/aluminum or boron/polyimide to provide increased strength and stiffness with less weight. One proposed concept uses large areas of cover panels composed of two beaded sheets with the beads oriented in the chordwise direction. The inner skin is deeply beaded and the outer skin which is exposed to the airflow is lightly beaded. The spar caps are heavily reinforced with uniaxial boron/polyimide. The wing tips would be of aluminum-brazed titanium honeycomb.

The proposed far-term concepts are predominantly advanced composite designs using both uniaxial and biaxial applications. Composite material systems that have sufficient temperature resistance include boron/aluminum and borsic/aluminum, graphite/PPQ, and boron/polyimide. All these composite systems require additional development in both material technology and fabrication methods before they could be used in airframe primary structures.

Structures for Hypersonic Cruise Aircraft

Hypersonic vehicles ($M \geq 5$) will be subject to severe aerodynamic heating which can result in surface radiation equilibrium temperatures in excess of 540° C. In shuttle-type applications where the heat load during reentry is of short duration and where the structure must survive only a limited number of flights, a reusable surface insulation thermal protection system (such as rigidized silica material) bonded to the metallic vehicle surface is sufficient to accommodate the transient heat load (ref. 87). However, for hypersonic cruise applications, this concept is not viable. Past structural research for hypersonic vehicles has primarily centered on a hot-structures approach wherein the severe aerodynamic heating associated with high Mach number flight is accommodated by allowing the vehicle surface to reach radiation equilibrium temperatures. The results of a 1970 study (ref. 88) to determine efficient hot-structure concepts for hypersonic wing structure are shown in figure 35. The Rene' 41 structural panels are beaded to obtain maximum stiffness per unit weight and to allow for thermal expansion without thermal stress. Lightweight corrugated heat shields provide the aerodynamic surface and, in combination with insulation, control the temperature of the structure. The leading edge is segmented to minimize thermal stress. The study revealed that major problem areas were thermal stress and material behavior under longtime cyclic exposure to elevated temperatures which tend to limit the lifetimes of such structures to levels far below those associated with current transport aircraft. An experimental program to evaluate a hot-wing structure (similar to that shown in fig. 35) under simulated loading and heating is currently underway at the Flight Research Center. An extensive evaluation of metallic-heat-shield concepts is currently being conducted in the Langley 8-foot high-temperature structures tunnel which can expose a model to high-temperature flow at Mach 7. Also, Langley has sponsored considerable development of the beaded-panel concepts as discussed in a subsequent section.

Hypersonic vehicles will use liquid hydrogen as a fuel because its high heat of combustion results in an increase in engine performance by a factor of 2.75 over conventional jet fuel. Additionally, hydrogen has a heat-sink capacity in excess of 13.9 kJ/kg (6000 Btu/lb) when raised from storage temperatures to combustion temperatures. This heat-sink capacity will permit regenerative cooling of the engines and some degree of airframe cooling. NASA is, therefore, currently investigating the practicality of using this heat sink to actively cool structural panels as an alternative to the hot-structure approach. Active cooling will permit use of conventional materials such as aluminum and allow the structure to work at relatively low temperatures where long life can be expected. Active cooling has been employed on a limited basis in operational vehicles to provide temperature control of pilot, passenger, and critical equipment compartments as well as engine components. However, application to large aircraft surface areas will require further research and development efforts.

Figure 36 suggests an active cooling system for a projected hypersonic aircraft. A secondary coolant circulates under the surface skin and picks up heat which is then rejected to the liquid hydrogen fuel in the heat exchangers as the fuel flow to the engines. The sketch to the right indicates that redundancy in the circulating system components is required to enhance system reliability. The sketch to the left indicates the complexity involved with actively cooling load-carrying structures. In designing such structures, consideration must be given to cooling-system parameters such as coolant inlet and outlet temperatures and pressures, coolant flow properties, structural temperature rise between coolant passages, distribution line sizes, pumps, and heat exchanger sizes, in addition to the standard structural design parameters to obtain a minimum overall structural system weight. NASA is currently developing design tools which will encompass both active cooling and structural design parameters. Additionally, contractual efforts are underway to provide lightweight hardware which will be tested in-house to determine the thermal and structural performance and to assess the overall structural integrity and reliability of actively cooled load-carrying structures. Results from these tests will be used to evaluate design tools and to determine the potential of the active cooling approach for future hypersonic flight applications.

Lightweight Beaded Panels

For several years Langley Research Center has been investigating structural concepts which use elements with curved cross sections to develop beaded or corrugated skin panel structures (refs. 88 to 92). The curved sections exhibit high local buckling strengths which lead to highly efficient structural concepts. These concepts can be applied where a rough external surface is aerodynamically acceptable or where the primary structure is protected by heat shields. The corrugated nature of the panels makes them especially attractive for high-temperature applications because controlled thermal growth is permitted which minimizes thermal stress. The technology resulting from this program is applicable to various formable materials and to many aerospace applications such as launch and space vehicles as well as hypersonic aircraft.

A contractual study is being conducted by The Boeing Company to develop technology for lightweight structural panels designed for combined loads of axial compression, inplane shear, and bending due to lateral pressure. Governing analytical static-strength and stability equations for panels under combined load and material and geometric constraint equations were incorporated in a random-search-type optimization computer program to identify minimum-weight designs for several potentially efficient concepts. However, in order for these concepts to realize their analytical potential, all the significant failure modes had to be properly recognized and accounted for. Consequently, buckling tests were conducted on subscale panels to identify local failure modes and provide data for modification of local buckling theory where required. Full-scale 1.016- by 1.016-m (40- by 40-in.) panels were tested to obtain large-panel failure data for correlation with theory.

Figure 37 shows a large panel in the test fixture (lower right) which was used to subject the panels to combined compression, shear, and bending. A 1.016- by 1.016-m (40- by 40-in.) tubular panel, the same size as the panel shown at the upper right of the figure, weighed only 66.28 N (14.9 lb), but carried over 445 kN (100 000 lb) in compression before failure.

Test results of the circular tubular configuration under various combined loads were correlated with theory and the appropriate modifications to the theory have been identified. In figure 37 the structural weight based on the original theory (solid curve) and that based on the modified theory (dashed curve) are shown as a function of compressive load N_x. Note that the originally predicted panel efficiency is not only verified by experiment but is actually exceeded by several percent. Thus, a potential weight savings for this configuration (25 to 30 percent compared with conventional stringer-stiffened construction) has been successfully demonstrated. These results were obtained from panels fabricated from aluminum and tested at room temperature. The theory is currently being applied to the design of panels fabricated of superalloy material for subsequent verification tests at elevated temperature in a hot-wing test fixture at the NASA Flight Research Center.

Even though the circular tubular concepts demonstrated high structural efficiency, the study revealed two potential problems which require further attention. Nonoptimum panel-end closeouts, which were found to contribute as much as 30 percent to the total panel mass, require detailed stress analyses to improve the load path and define optimum closeout designs. Also, distortions of the panel cross sections under loads, particularly of noncircular cross sections, may seriously degrade the efficiency of such thin-walled structures and may require extensive nonlinear analytical, as well as experimental, studies to account for failure-mode interactions due to these distortions. Such problems would appear to be of interest to researchers in the academic environment.

Weld-Brazing - An Improved Fabrication Process

Weld-brazing is a joining process (ref. 75), developed by Thomas T. Bales of the Langley Research Center, which combines resistance spotwelding with brazing. The process has been used successfully to join titanium structural members with an aluminum braze alloy and should be applicable for fabricating structures from nickel base and refractory metal alloys with an appropriate braze alloy.

The weld-braze process is described pictorially in figure 38. The first step in the process is to establish spotwelding parameters which result in expansion of the weld nuggets to provide a predetermined uniform gap between the faying surfaces in order to optimize the thickness of the subsequent brazed joint. Figure 38(a) depicts a Ti-6Al-4V titanium-alloy skin-stringer specimen that has been spotwelded to establish a faying-surface gap suitable for aluminum-alloy brazing. Following resistance welding, braze alloy foil or powder in appropriate quantities is placed along the exposed edge of the joint as shown in figure 38(b). The assembly is then brazed in a vacuum or inert-gas furnace to produce the specimen shown in figure 38(c). During brazing, the braze alloy melts and is drawn into the existing gap by capillary action. The result of this can be observed in figure 38(d) which is a photomacrograph of the weld-brazed joint. The braze is shown to have been drawn through the gap to form a fillet between the face sheet and the inner radius of the hat stringer. Figure 38(e) is a photomicrograph showing the good integrity of the joint at the weld nugget-braze interface.

The anticipated advantages of weld-brazing are:

The complex dies and tooling normally needed for brazing are eliminated in that the spotwelds maintain alinement of mating parts during brazing and thereby simplify the brazing process.

Structures fabricated by weld-brazing should be superior to the fatigue and static mechanical properties of conventional riveted structures because of the nature of the continuous bond of the weld-brazed joint.

The elevated-temperature properties of a weld-brazed joint are normally superior to those of a brazed joint because of the strength contribution of the spotwelds.

Weld-brazed joints are hermetically sealed and thereby eliminate corrosion problems encountered between the faying surfaces of spotwelded or riveted joints.

Figure 39 shows a comparison of the properties of weld-brazed and conventional joints.

CONCLUDING REMARKS

The scope of the national programs for developing structural technologies for tomorrow's aircraft is extensive and beyond the bounds of a single paper. However, the writer has tried to highlight some of the promising developments and to present some detail in areas believed to be particularly opportune. Numerous references to recent studies which provide state-of-the-art structural options for design of future aircraft are cited. It is hoped that some contribution has been made herein to reveal both the nature of the problems to be solved to achieve more cost-effective, high-performance aircraft and the challenge provided to innovative researchers who wish to get their teeth into some tough problems.

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CHARACTERISTIC	STRUCTURAL FEATURE	MATERIAL FEATURE
FAST, INTEGRATED DESIGN PROCESS	GOOD CRITERIA	PREDICTABLE CHARACTERISTICS
LIGHTWEIGHT STRUCTURES	OPTIMUM MATERIAL DISTRIBUTION	LIGHT, STRONG, STIFF
LOW MANUFACTURING COSTS	MINIMUM PARTS MINIMUM TOOLING FOR FABRICATION FEW, DEPENDABLE FASTENERS	LOW COST HIGHLY PROCESSIBLE
HIGH STRUCTURAL DURABILITY	FAIL-SAFE DESIGN	TOUGH
HIGH INTEGRITY	ACCESSIBLE	
HIGH AVAILABILITY	INSPECTIBLE	
LOW MAINTENANCE COSTS	MODULAR SUBSTITUTION	REPAIRABLE RESISTANT TO OPERATIONAL ENVIRONMENT

Figure 1.- Goals for cost-effective structural design.

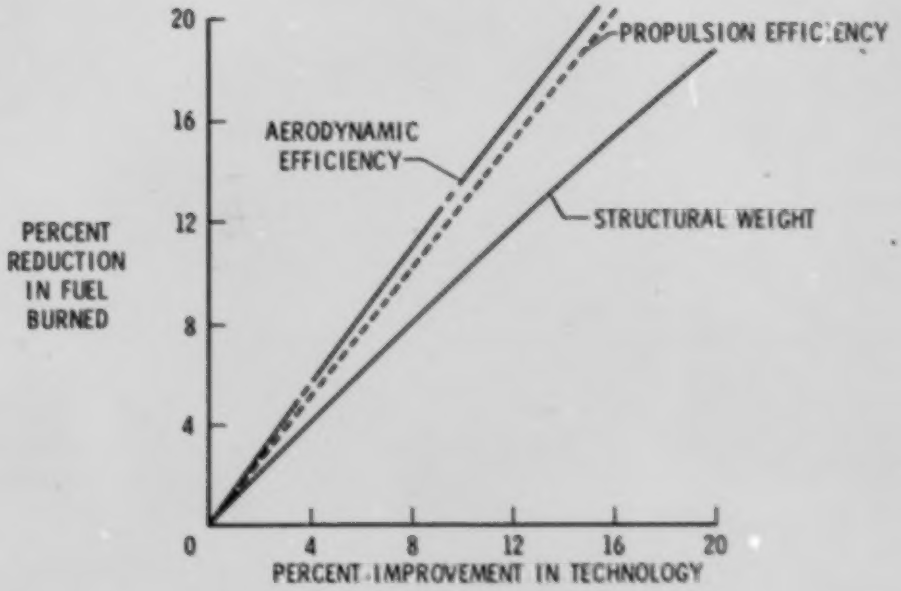


Figure 2.- Effect of technology on fuel consumption.

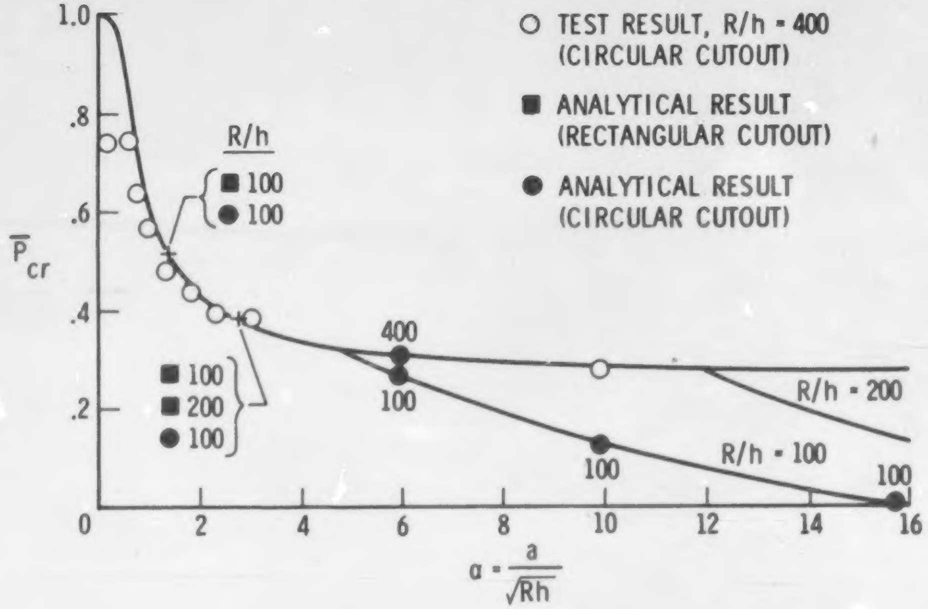


Figure 3.- Theoretical and experimental critical loads of shell with cutouts (ref. 32).

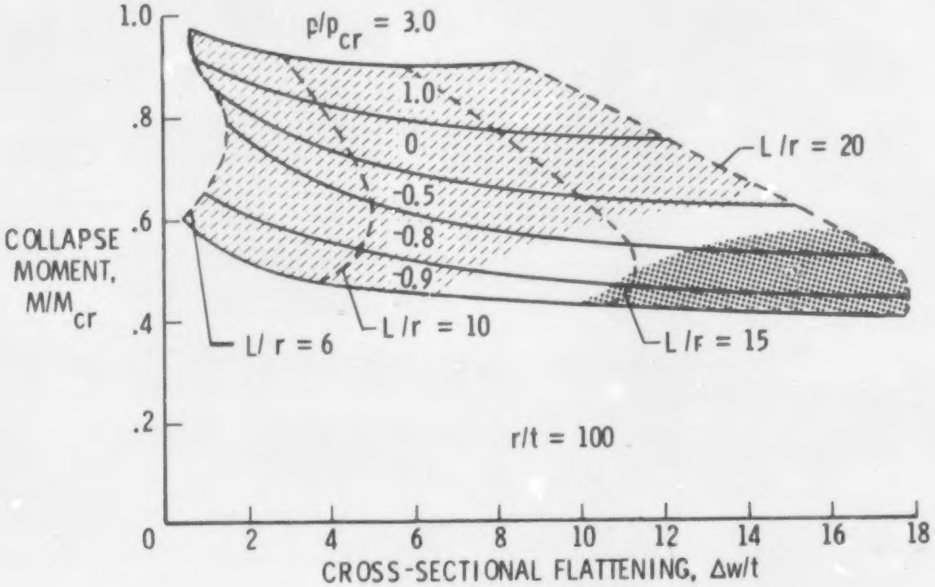


Figure 4.- Comparison of collapse moments of cylinders with combined bending and pressure (ref. 33).

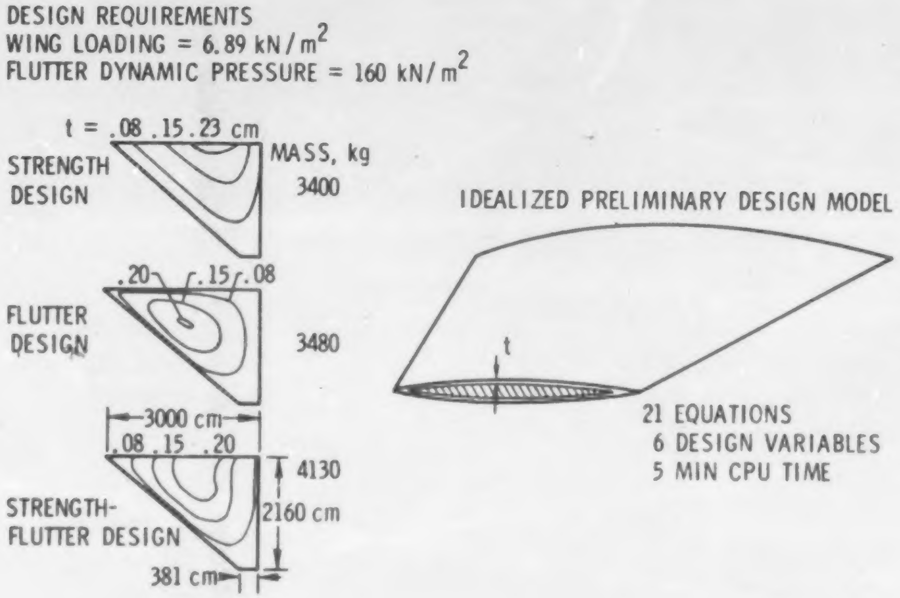

DESIGN REQUIREMENTS
WING LOADING = 6.89 kN/m²
FLUTTER DYNAMIC PRESSURE = 160 kN/m²
t = .08 .15 .23 cm
STRENGTH DESIGN
MASS, kg
3400
IDEALIZED PRELIMINARY DESIGN MODEL
.20 .15 .08
FLUTTER DESIGN
3480
t
3000 cm
.08 .15 .20
4130
STRENGTH-FLUTTER DESIGN
2160 cm
381 cm
21 EQUATIONS
6 DESIGN VARIABLES
5 MIN CPU TIME

Figure 5.- Contour plots showing wing cover thickness distributions for flutter, strength, and combined designs (ref. 35).

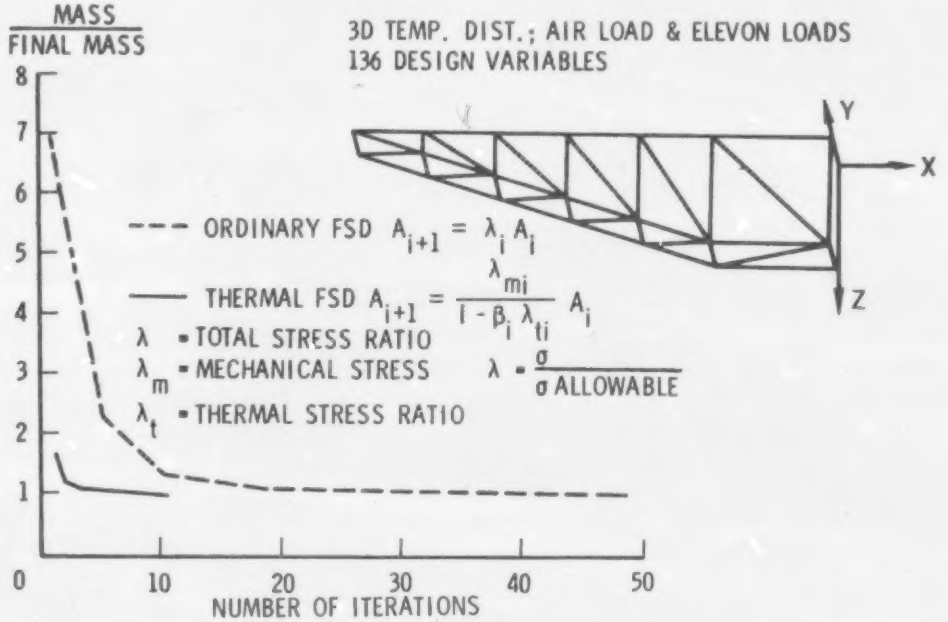
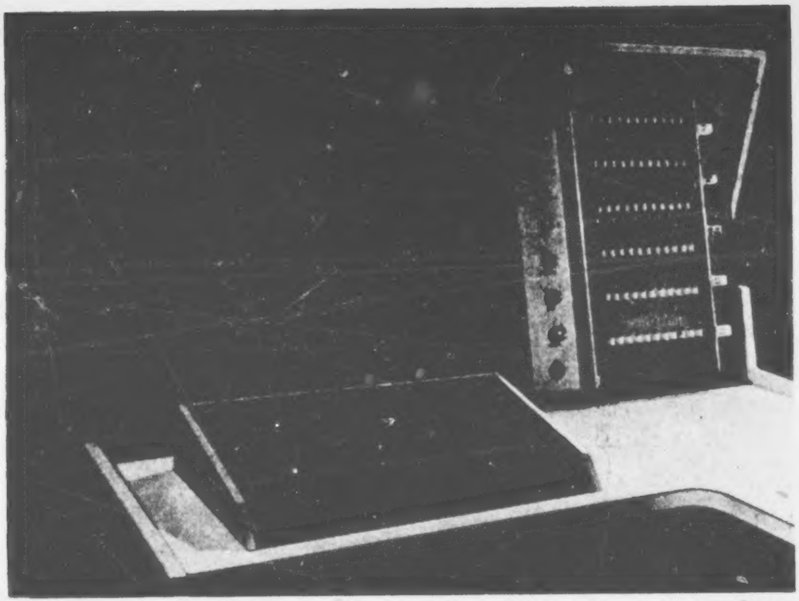


Figure 6.- Improved fully-stressed design procedure for heated structures.



L-73-6391

Figure 7.- Finite-element model generated by NASTRAN.

- EFFICIENCY CHANGES
  - CYCLIC SYMMETRY OPTIONS FOR BOTH STATICS AND NORMAL MODES
  - NEW SYMMETRIC DECOMPOSITION AND INNER LOOPS
  - NEW GINO
  - NEW STRUCTURAL MATRIX ASSEMBLER
  - NEW READING ROUTINES (NON-TRANSMIT & CORE RESIDENT)

- NEW CAPABILITY ADDITIONS
  - FULLY-STRESSED DESIGN OPTION FOR STATICS
  - CYCLIC SYMMETRY CAPABILITY (CONGRUENT ALSO AVAILABLE)
  - SUBSONIC FLUTTER CAPABILITY
  - SEVEN NEW ELEMENTS
  - GRIDPOINT FORCE BALANCE CHECKS

- ENHANCEMENTS TO PREVIOUS CAPABILITIES
  - IMPROVED DIFFERENTIAL STIFFNESS - ALLOW LOOPING
  - CEAD EXPANDED (UPPER HESSENBERG NOW AVAILABLE)

Figure 8.- Scope of NASTRAN changes - L15.5 to L16.

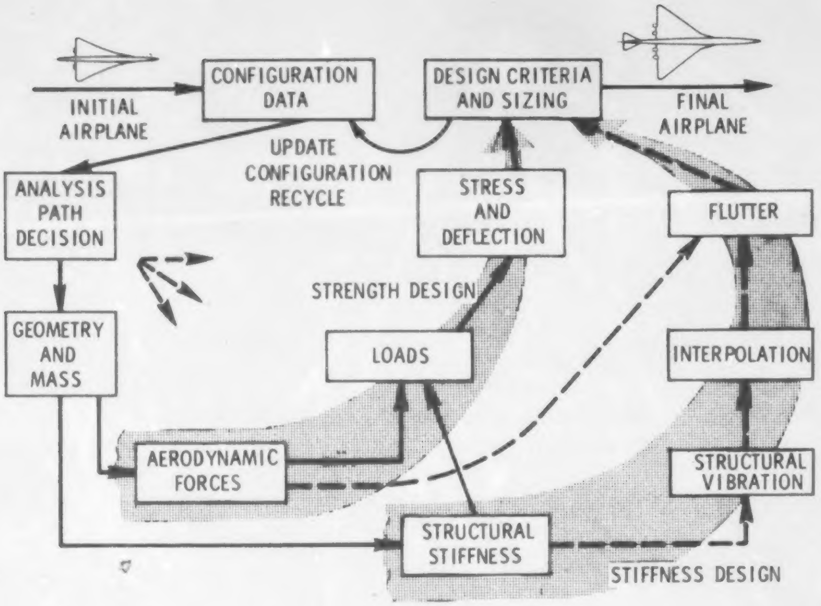

INITIAL AIRPLANE
CONFIGURATION DATA
DESIGN CRITERIA AND SIZING
FINAL AIRPLANE
UPDATE CONFIGURATION RECYCLE
ANALYSIS PATH DECISION
STRESS AND DEFLECTION
FLUTTER
STRENGTH DESIGN
GEOMETRY AND MASS
LOADS
INTERPOLATION
AERODYNAMIC FORCES
STRUCTURAL VIBRATION
STRUCTURAL STIFFNESS
STIFFNESS DESIGN

Figure 9.- Boeing integrated analysis system (ATLAS) (ref. 23).

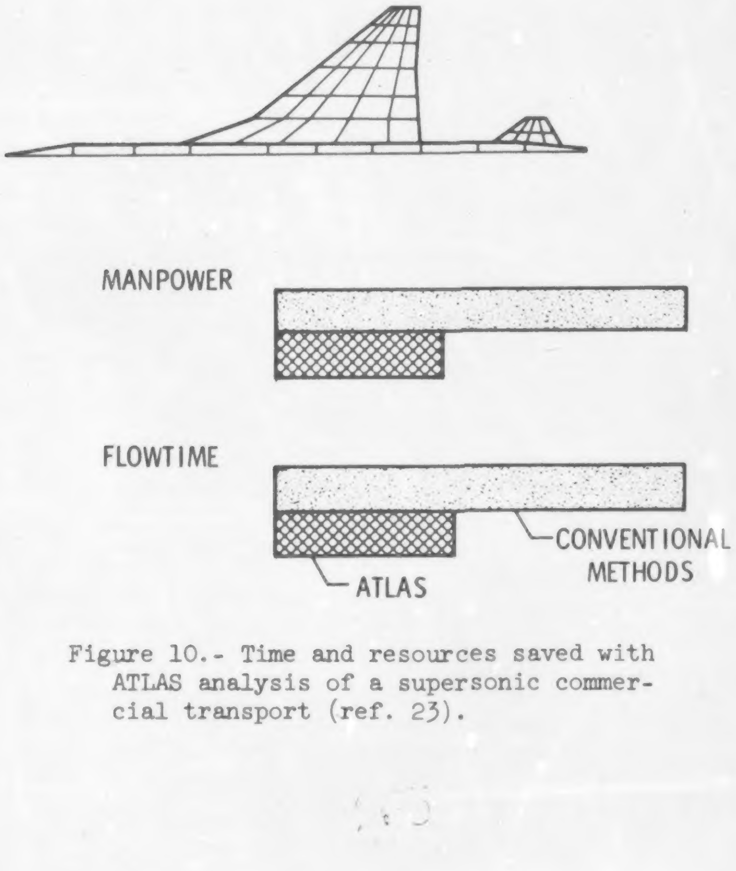


Figure 10.- Time and resources saved with ATLAS analysis of a supersonic commercial transport (ref. 23).

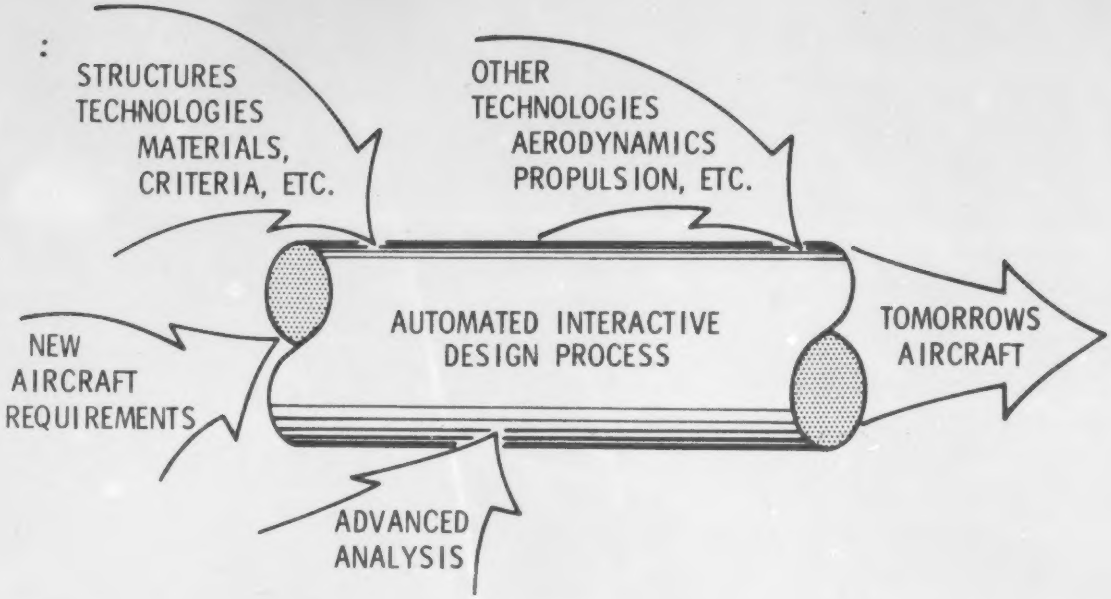

STRUCTURES TECHNOLOGIES
MATERIALS, CRITERIA, ETC.
OTHER TECHNOLOGIES
AERODYNAMICS PROPULSION, ETC.
NEW AIRCRAFT REQUIREMENTS
AUTOMATED INTERACTIVE DESIGN PROCESS
TOMORROWS AIRCRAFT
ADVANCED ANALYSIS

Figure 11.- Future aircraft design environment (ref. 19).

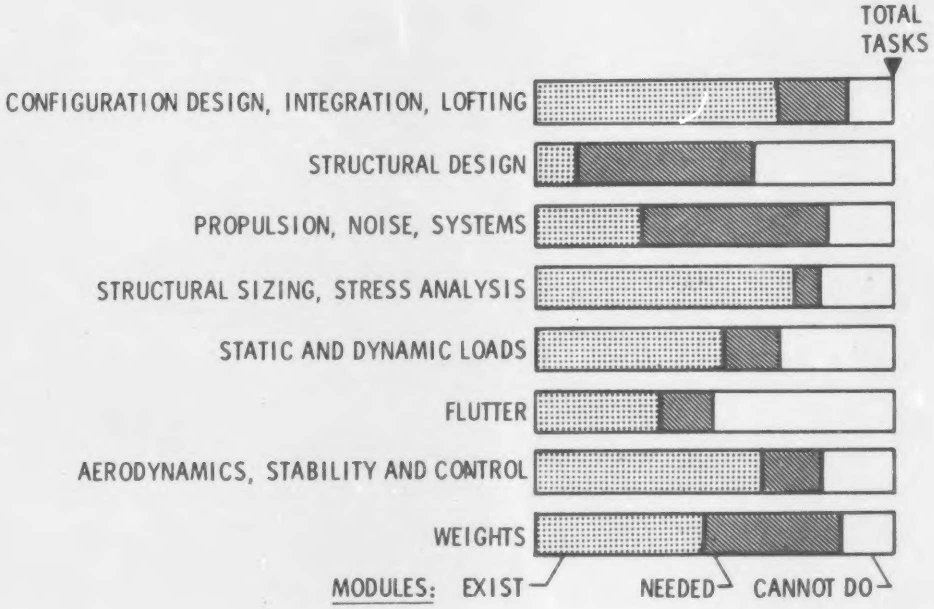


Figure 12.- Technical capability for automated preliminary design of a subsonic transport.

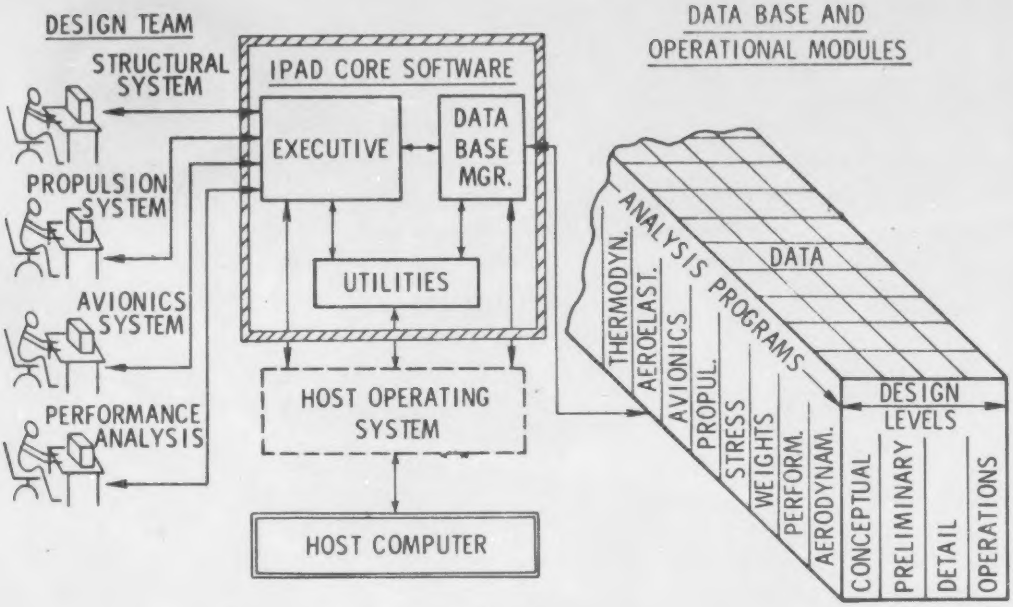

DESIGN TEAM
STRUCTURAL SYSTEM
PROPULSION SYSTEM
AVIONICS SYSTEM
PERFORMANCE ANALYSIS
IPAD CORE SOFTWARE
EXECUTIVE
DATA BASE MGR.
UTILITIES
HOST OPERATING SYSTEM
HOST COMPUTER
DATA BASE AND OPERATIONAL MODULES
ANALYSIS PROGRAMS
DATA
THERMODYN.
AEROELAST.
AVIONICS
PROPUL.
STRESS
WEIGHTS
PERFORM.
AERODYNAM.
DESIGN LEVELS
CONCEPTUAL
PRELIMINARY
DETAIL
OPERATIONS

Figure 13.- NASA integrated programs for aerospace-vehicle design (IPAD).

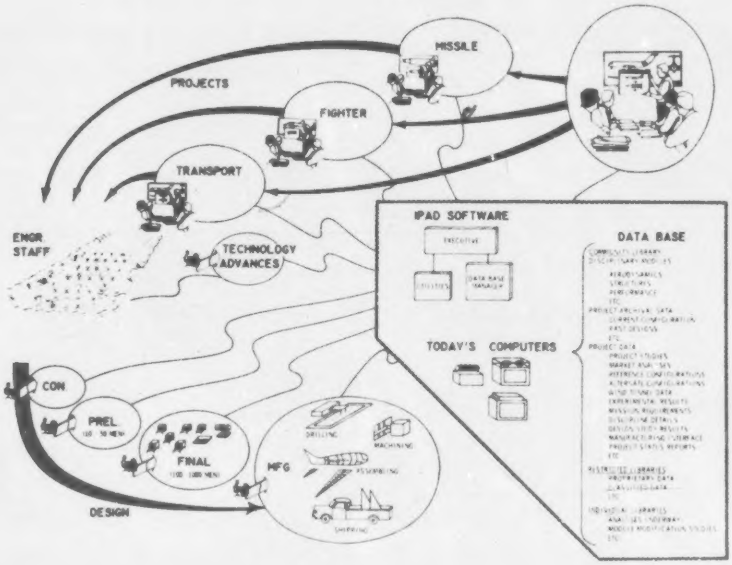

PROJECTS
MISSILE
FIGHTER
TRANSPORT
ENGR. STAFF
TECHNOLOGY ADVANCES
CON
PREL.
FINAL
MFG
DRILLING
MACHINING
ASSEMBLING
SHIPPING
DESIGN
IPAD SOFTWARE
EXECUTIVE
UTILITIES
DATA BASE MANAGER
TODAY'S COMPUTERS
DATA BASE
COMMUNITY LIBRARY
DISCIPLINARY MODULES
AERODYNAMICS
STRUCTURES
PERFORMANCE
ETC
PROJECT ARCHIVAL DATA
CURRENT CONFIGURATION
PAST DESIGNS
ETC
PROJECT DATA
PROJECT STUDIES
MARKET ANALYSES
REFERENCE CONFIGURATIONS
ALTERNATE CONFIGURATIONS
WIND TUNNEL DATA
EXPERIMENTAL RESULTS
MISSION REQUIREMENTS
DISCIPLINE DETAILS
DESIGN STUDY RESULTS
MANUFACTURING INTERFACE
PROJECT STATUS REPORTS
ETC
RESTRICTED LIBRARIES
PROPRIETARY DATA
CLASSIFIED DATA
ETC
INDIVIDUAL LIBRARIES
ANALYSES UNDERWAY
MODULE MODIFICATION STUDIES
ETC

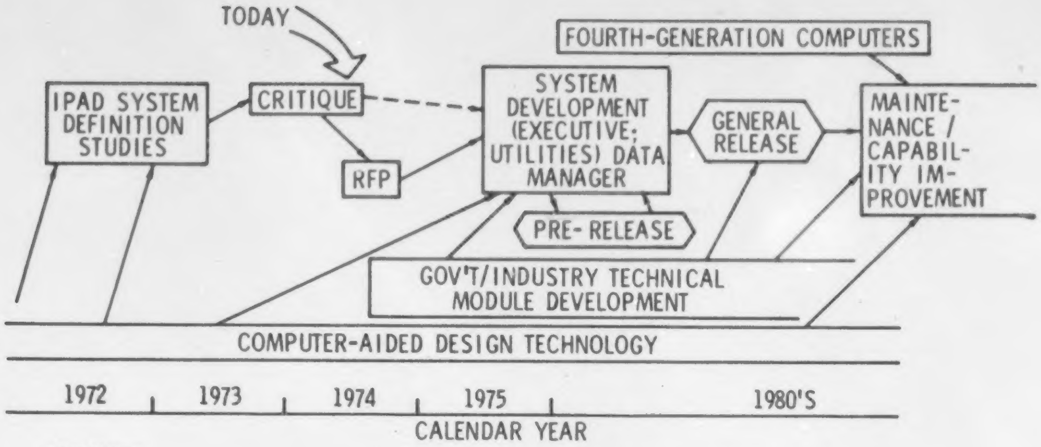
Figure 14.- Role of IPAD in product development.

BOEING	GENERAL DYNAMICS
1. DIRECT DESIGN LABOR AND FLOW TIME SAVINGS	1. FASTER ANALYSIS
2. REDUCTION OF RISK	2. INCREASED CONFIDENCE LEVEL IN THE INTERDISCIPLINARY COMPUTATION RESULTS
3. IMPROVED PRODUCT DESIGN	3. ABILITY TO TRACE RESULTS OF CHANGES THROUGHOUT THE WHOLE SYSTEM
4. ON-TIME DESIGN	4. SUBSTANTIALLY INCREASED ABILITY TO ISOLATE THE OPTIMAL DESIGN

Figure 15.- Projected benefits of IPAD.

BOEING	GENERAL DYNAMICS
● SHOULD NOT ABRUPTLY CHANGE DESIGN PRACTICE	● TO BE BUILT AROUND EXISTING ENGINEERING TEAM
● A LOGICAL, INEVITABLE NEXT STEP IN THE COMPUTER USE EVOLUTION	● SHOULD NOT BREAK UP TEAM OR FORCE INTO NEW MOLD
● WILL PROVIDE FOR FLOW OF COMPATIBLE DATA BETWEEN COMPUTING PROGRAMS	● NEW TOOLS TO DO FAMILIAR THING IN FAMILIAR WAYS WITH TEDIUM REDUCED
● WILL KEEP CONTINUAL TRACK OF: WHAT WAS COMPUTED HOW BY WHOM WHEN (PAST, FUTURE)	● IF CHANGE OF WAYS OCCURS, IT WILL COME FROM WITHIN THE IPAD USERS COMMUNITY

Figure 16.- Contractors' view of IPAD implementation.


TODAY
FOURTH-GENERATION COMPUTERS
IPAD SYSTEM DEFINITION STUDIES
CRITIQUE
RFP
SYSTEM DEVELOPMENT (EXECUTIVE; UTILITIES) DATA MANAGER
GENERAL RELEASE
MAINTENANCE / CAPABILITY IMPROVEMENT
PRE-RELEASE
GOV'T/INDUSTRY TECHNICAL MODULE DEVELOPMENT
COMPUTER-AIDED DESIGN TECHNOLOGY
1972
1973
1974
1975
1980'S
CALENDAR YEAR

THRUSTS:

- DESIGN SYSTEM FOR THE 80'S - REDUCE DESIGN CYCLE TIME & COSTS
- IMPROVED COMPUTATION, COMMUNICATION AND DATA MANAGEMENT FOR ALL DESIGN LEVELS
- ADAPTABLE TO INDIVIDUAL COMPANY NEEDS - EXPANDABLE & OPEN ENDED
- APPLICABLE TO INTEGRATED DESIGN OF COMPLEX CIVIL SECTOR SYSTEMS

Figure 17.- IPAD development plan.

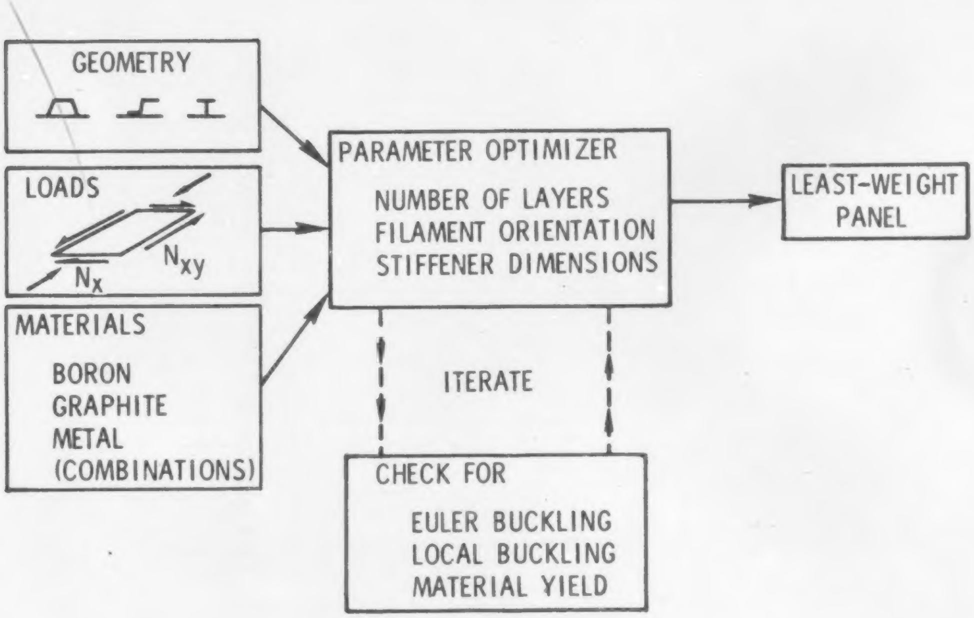

GEOMETRY
LOADS
N_x
N_{xy}
MATERIALS
BORON
GRAPHITE
METAL
(COMBINATIONS)
PARAMETER OPTIMIZER
NUMBER OF LAYERS
FILAMENT ORIENTATION
STIFFENER DIMENSIONS
LEAST-WEIGHT PANEL
ITERATE
CHECK FOR
EULER BUCKLING
LOCAL BUCKLING
MATERIAL YIELD

Figure 18.- Composite panel optimization program.

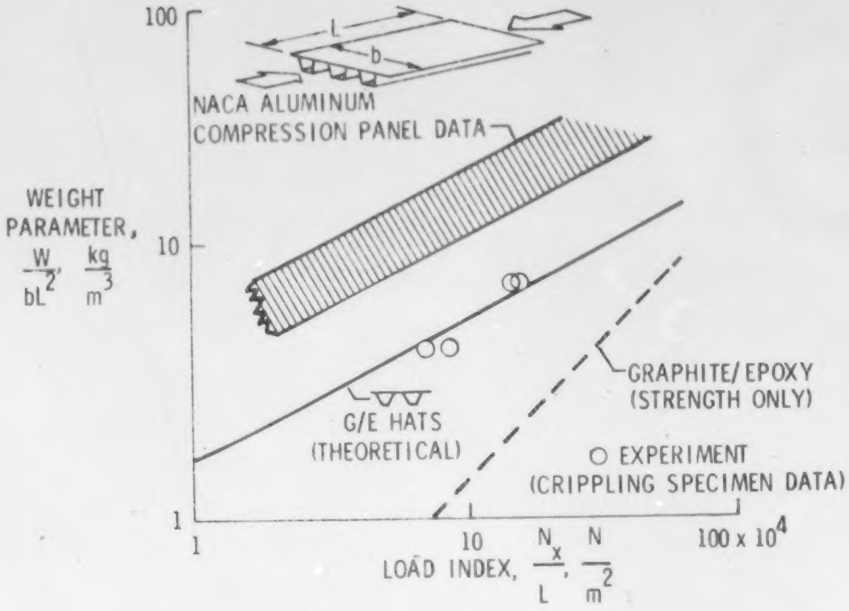
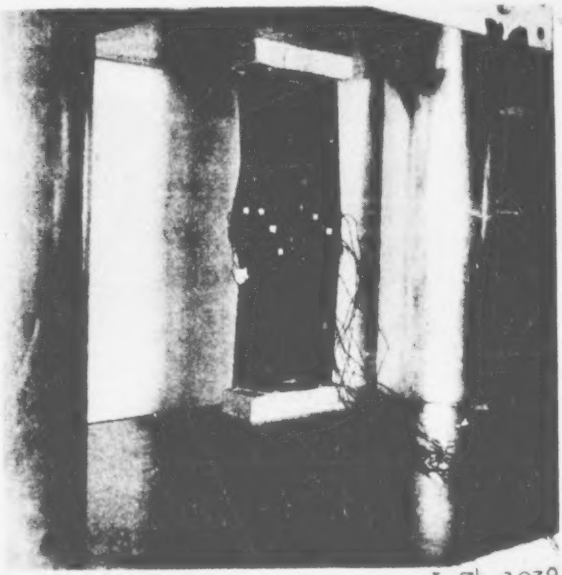


Figure 19.- Weight-strength comparisons for aluminum and graphite/epoxy compression panels.



L-74-1938

Figure 20.- Buckled hat-section crippling specimen.

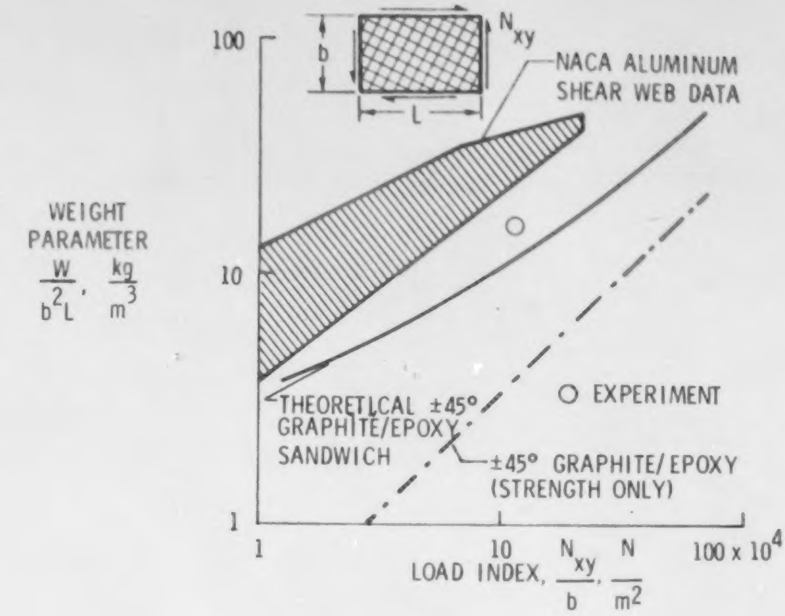


Figure 21.- Weight-strength comparisons for aluminum and graphite/epoxy shear webs.

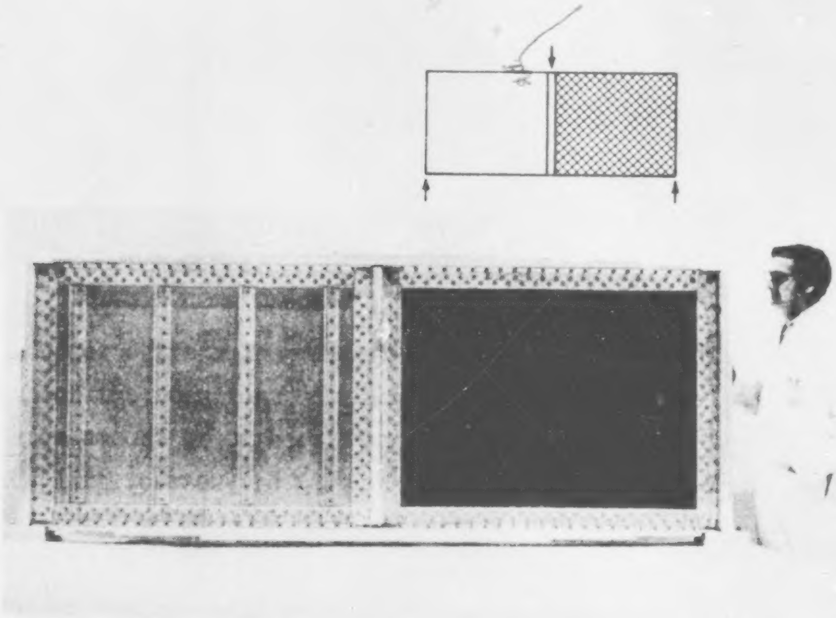


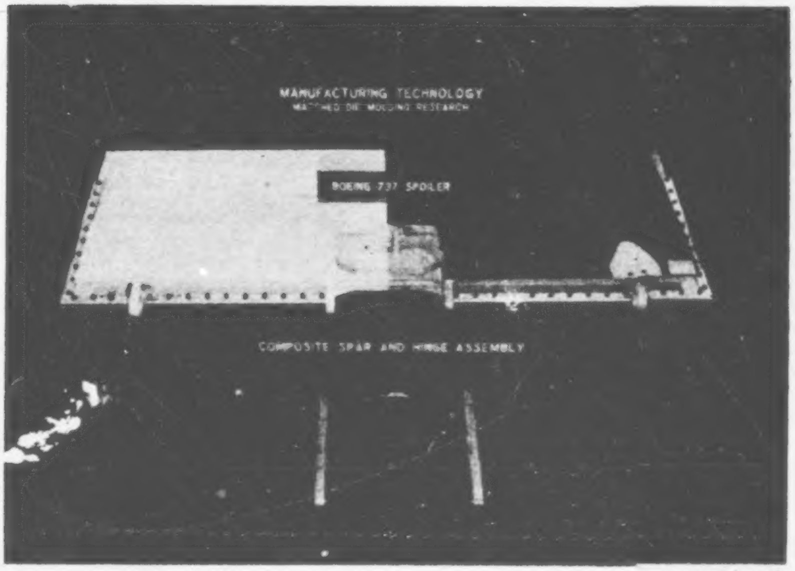
Figure 22.- Graphite/epoxy sandwich shear web.

GRAPHITE
FIBERGLASS
KEVLAR-49
CENTIMETERS
INCHES

	METAL		COMPOSITE	
	ALUMINUM	GRAPHITE	FIBERGLASS	KEVLAR 49
WEIGHT, kg	.14	.09	.10	.07
MAXIMUM FAILURE TORQUE, joules	1020*	1144	2376	1914
MATERIALS	2024	MODMOR II/ NARMCO 5206	E GLASS / 3M-1157	KEVLAR 49 / 3M-SP305
RAW MATERIAL COST, $/kg	66**	425	7	198

* DESIGN ULTIMATE TORQUE
** COST FOR ALUMINUM COUPLINGS

Figure 23.- Chopped-fiber molded transmission shaft couplings.


MANUFACTURING TECHNOLOGY
MATCHED DIE MOLDING RESEARCH
BOEING 737 SPOILER
COMPOSITE SPAR AND HINGE ASSEMBLY

L-73-4394

Figure 24.- Molded composite spar and hinge assembly.

COMMERCIAL DESIGNATION	PRODUCER	TYPE	CURING TEMPERATURE, °C	CURING PRESSURE kN	POSTCURE	STATUS	REMARKS
SKYBOND 710	MONSANTO	THERMOSET	177	689	371°C, 8 hr	COMMERCIALLY AVAILABLE	• RELEASES VOLATILES • SHELF LIFE LOW • USES EPOXY-LIKE FABRICATION EQUIP.
P13N	CIBA-GEIGY	THERMOSET	302	4136	343°C, 4 hr	COMMERCIALLY AVAILABLE	• LOW FLOW • SHELF LIFE LOW • MANY VOLATILES
KERIMID 600	RHODIA CORP.	THERMOSET	177	689	315°C, 4 hr	COMMERCIALLY AVAILABLE	• EASY TO FABRICATE • POOR PROPERTIES ABOVE 260°C • BRITTLE AT LOWER TEMPERATURES
NR 150B	DuPONT	THERMOPLASTIC	427	1379	NONE	COMMERCIALLY AVAILABLE (RECENT)	• NEW MATERIAL WITH HIGH POTENTIAL • NO COMPONENTS FABRICATED TO DATE • SHELF LIFE UNKNOWN
LaRC-13	IN-HOUSE	THERMOSET	232	344	315°C, 4 hr	EXPERIMENTAL	• GOOD FABRICATION PROPERTIES • GOOD SHELF LIFE • SLIGHTLY LOWER PROPERTIES THAN P13N

Figure 25.- Current polyimide resins.

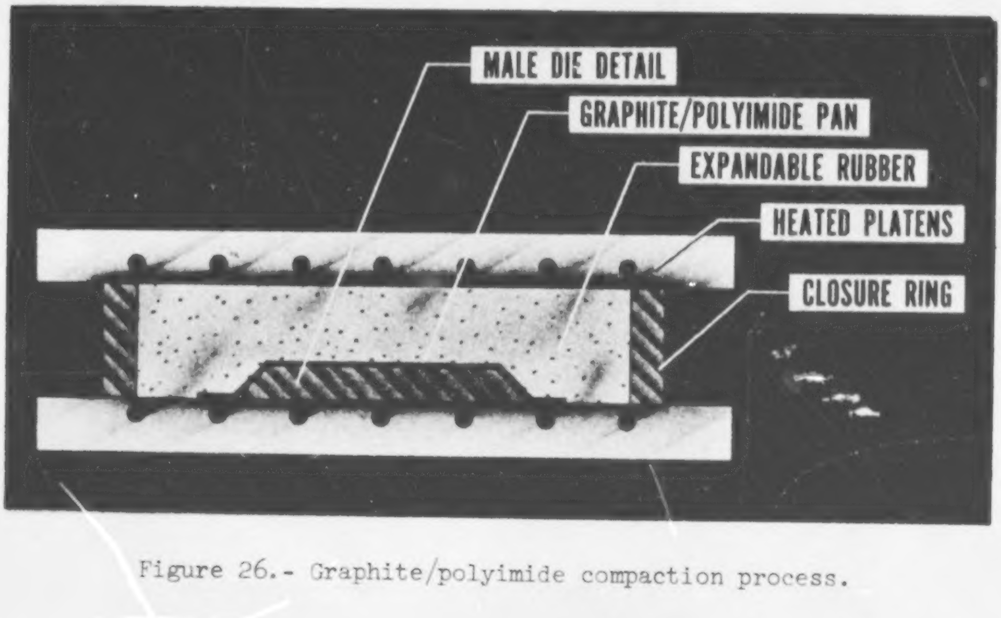
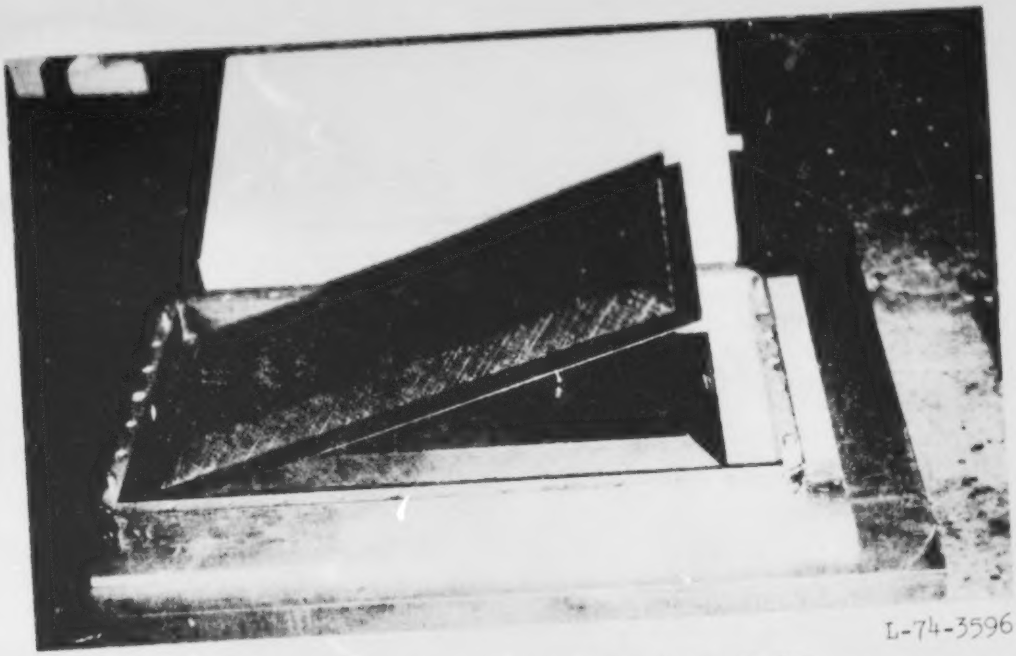


Figure 26.- Graphite/polyimide compaction process.



L-74-3596

Figure 27.- Graphite/polyimide panel for flight test on YF-12 aircraft.

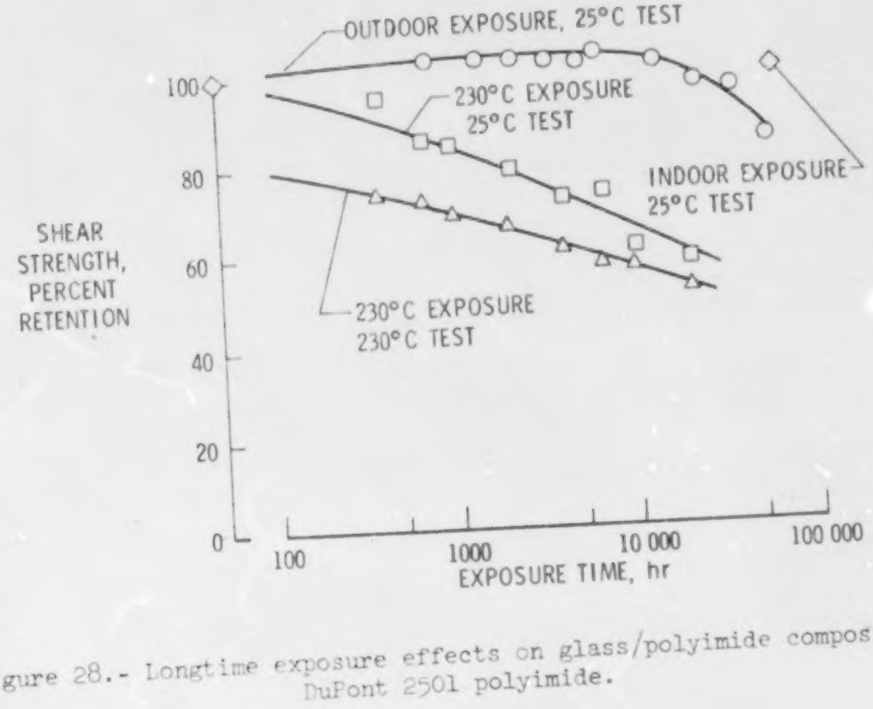


Figure 28.- Longtime exposure effects on glass/polyimide composites. DuPont 2501 polyimide.

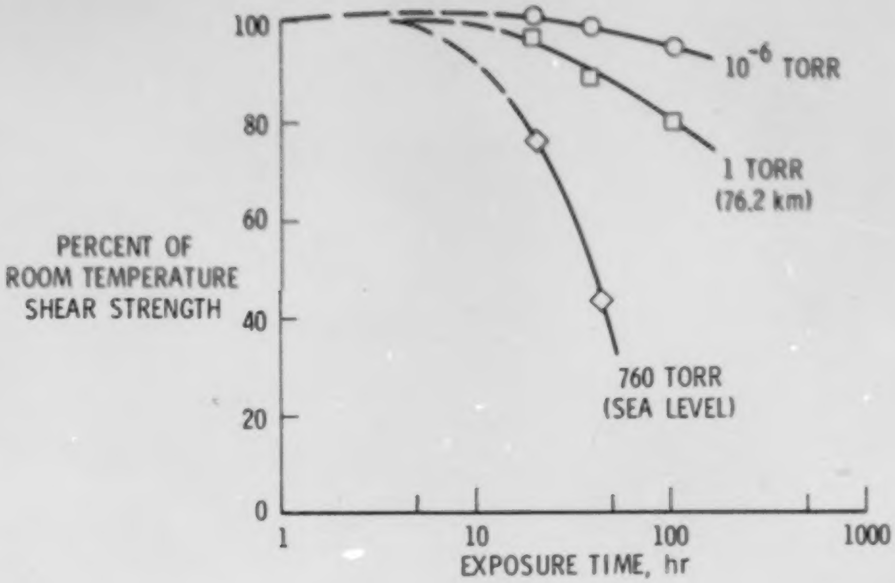


Figure 29.- Effects of elevated temperature exposure on strength of graphite/polyimide composite. 370° C; HTS graphite; skybond 710 polyimide.

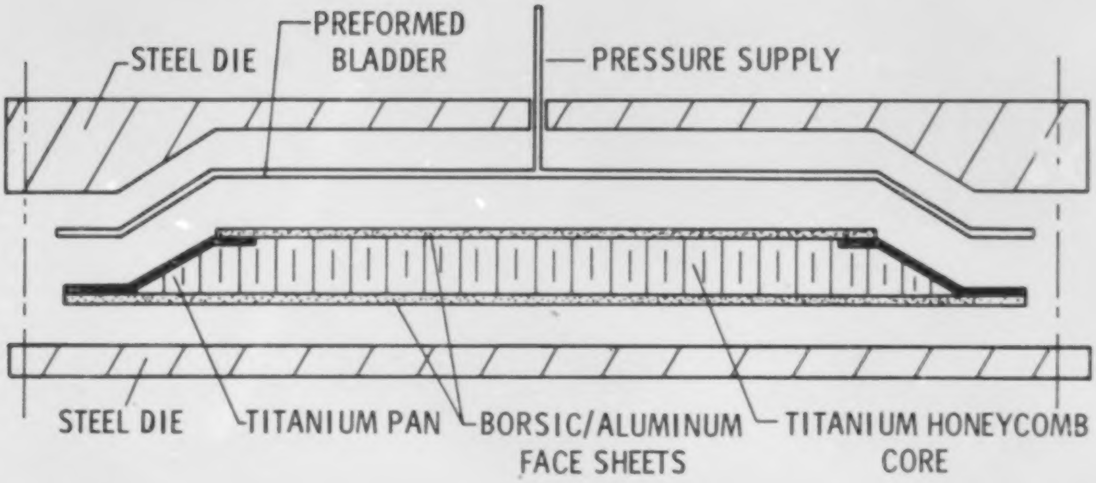

STEEL DIE
PREFORMED
BLADDER
PRESSURE SUPPLY
STEEL DIE
TITANIUM PAN
BORSIC/ALUMINUM
FACE SHEETS
TITANIUM HONEYCOMB
CORE

Figure 30.- Brazing fixture for borsic/aluminum panels.

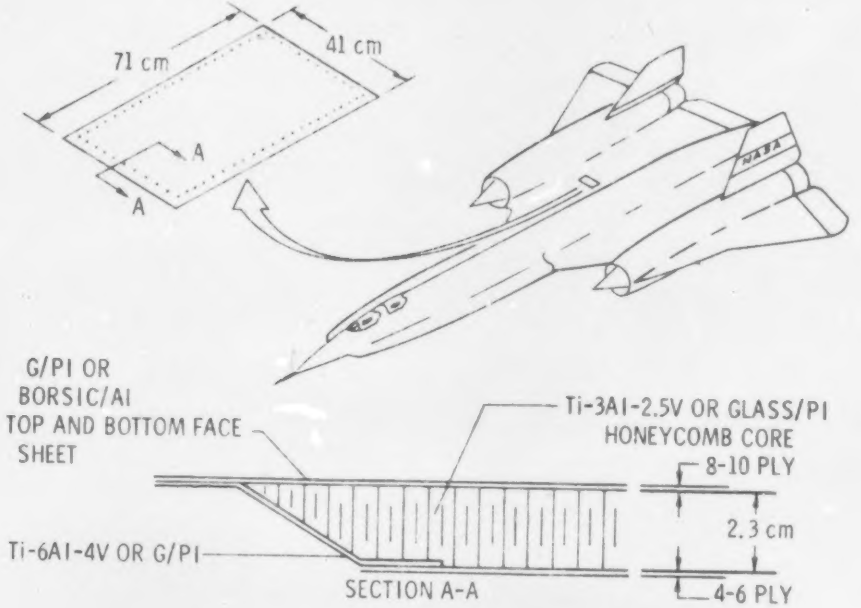

71 cm
41 cm
A
A
NASA
G/PI OR
BORSIC/Al
TOP AND BOTTOM FACE
SHEET
Ti-3Al-2.5V OR GLASS/PI
HONEYCOMB CORE
8-10 PLY
2.3 cm
Ti-6Al-4V OR G/PI
SECTION A-A
4-6 PLY

Figure 31.- G/PI and Borsic/Al YF-12 panel design.

	COMPONENT	FIRST FLIGHT	USER
1	CH-54B HELICOPTER TAIL CONE	MARCH 1972	US ARMY
2	L-1011 FUSELAGE PANEL	JAN 1973	EASTERN, TWA, AIR CANADA
3	737 SPOILER	JULY 1973	ALOHA, LUFTHANSA, NEW ZEALAND
4	737 ADVANCED SPOILER	OCT 1974	PIEDMONT, PSA, VASP (BRAZIL)
5	C-130 CENTER WING BOX	NOV 1974	US AIR FORCE
6	DC-10 RUDDER	MAY 1975	
7	DC-10 AFT PYLON PANEL	JUNE 1975	

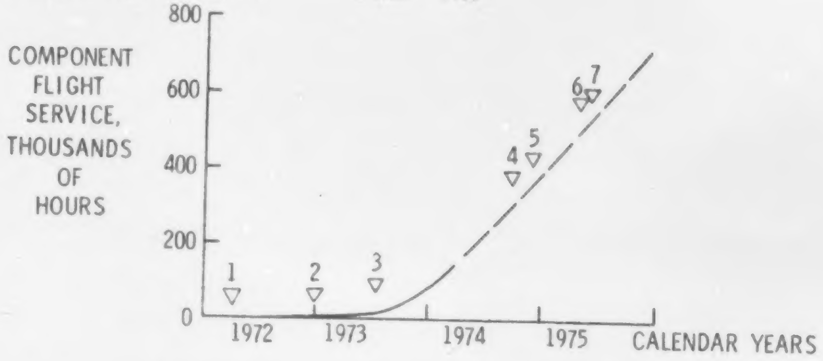


Figure 32.- Current program for flight service evaluation of composite structural components.

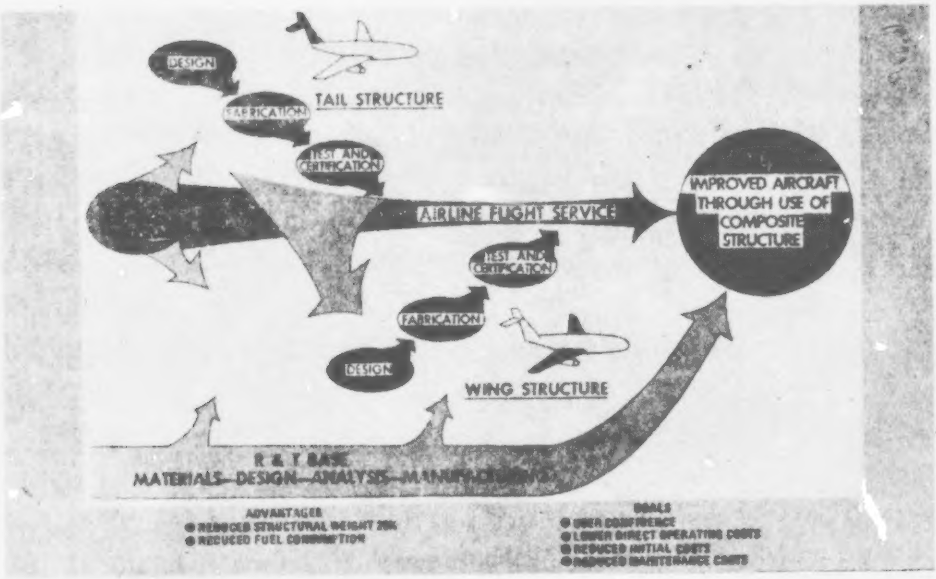

DESIGN
FABRICATION
TEST AND CERTIFICATION
TAIL STRUCTURE
AIRLINE FLIGHT SERVICE
IMPROVED AIRCRAFT THROUGH USE OF COMPOSITE STRUCTURE
TEST AND CERTIFICATION
FABRICATION
DESIGN
WING STRUCTURE
R & T BASE
MATERIALS—DESIGN—ANALYSIS—MANUFACTURING
ADVANTAGES
● REDUCED STRUCTURAL WEIGHT 20%
● REDUCED FUEL CONSUMPTION
GOALS
● USER CONFIDENCE
● LOWER DIRECT OPERATING COSTS
● REDUCED INITIAL COSTS
● REDUCED MAINTENANCE COSTS

Figure 33.- Planned composite primary structure flight service program.

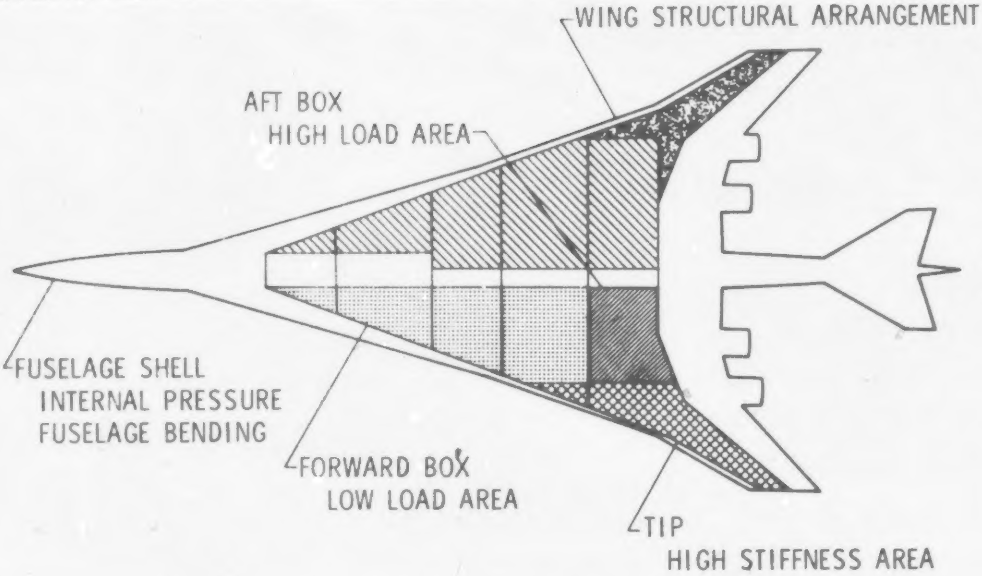

WING STRUCTURAL ARRANGEMENT
AFT BOX
HIGH LOAD AREA
FUSELAGE SHELL
INTERNAL PRESSURE
FUSELAGE BENDING
FORWARD BOX
LOW LOAD AREA
TIP
HIGH STIFFNESS AREA

Figure 34.- Projected arrow-wing structural arrangement.

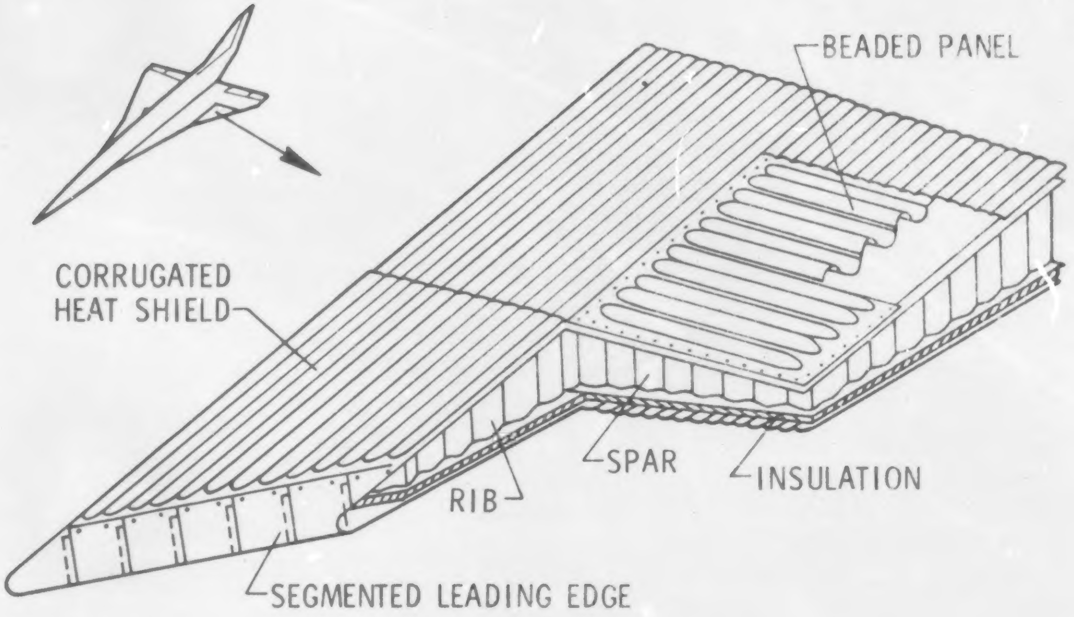

BEADED PANEL
CORRUGATED HEAT SHIELD
SPAR
INSULATION
RIB
SEGMENTED LEADING EDGE

Figure 35.- Advanced design hot-wing structure.

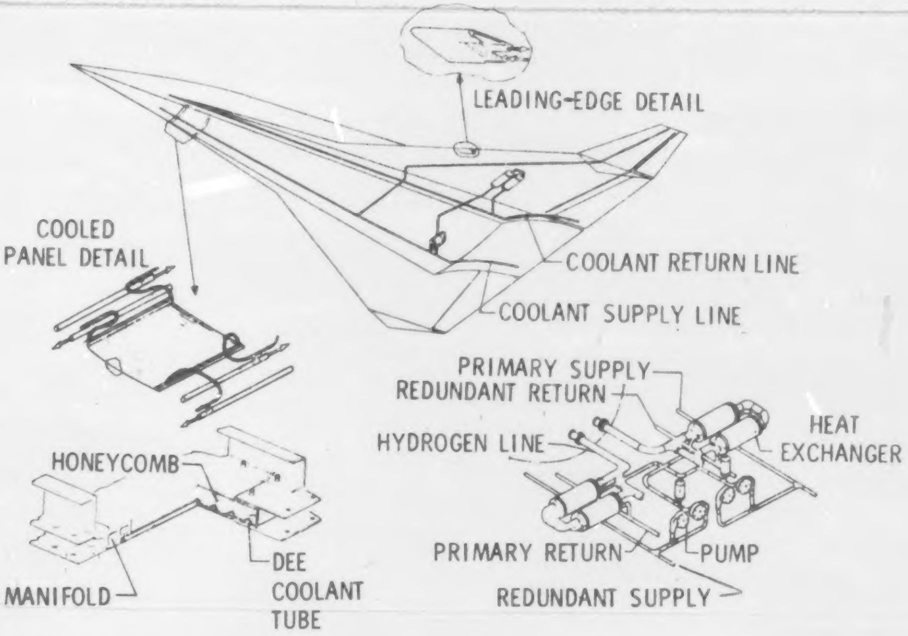

LEADING-EDGE DETAIL
COOLED PANEL DETAIL
COOLANT RETURN LINE
COOLANT SUPPLY LINE
PRIMARY SUPPLY
REDUNDANT RETURN
HYDROGEN LINE
HEAT EXCHANGER
HONEYCOMB
PRIMARY RETURN
PUMP
DEE COOLANT TUBE
MANIFOLD
REDUNDANT SUPPLY

Figure 36.- Active cooling system schematic.

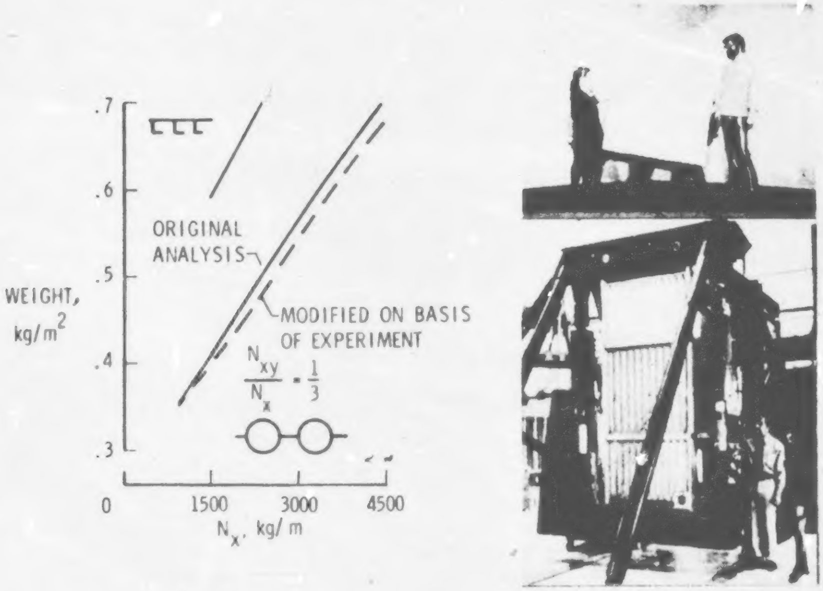
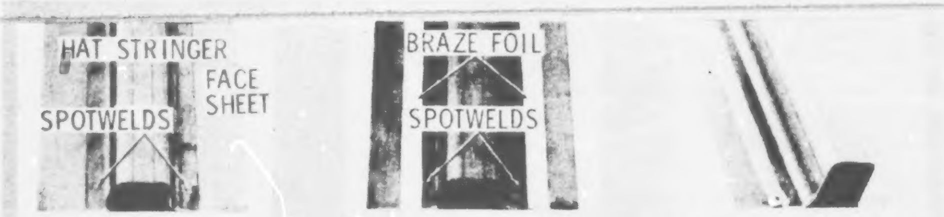


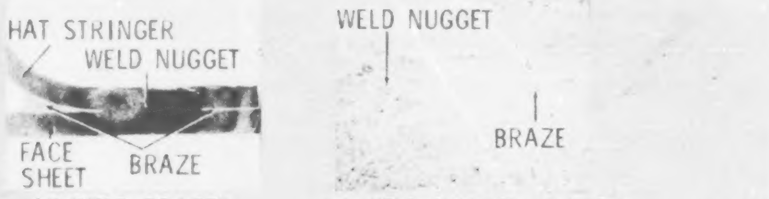
Figure 37.- Advanced structural panels.


HAT STRINGER
FACE SHEET
SPOTWELDS
BRAZE FOIL
SPOTWELDS

(a) SPOTWELD PRIOR TO BRAZING

(b) BRAZE FOIL IN PLACE

(c) WELD-BRAZED


HAT STRINGER
WELD NUGGET
FACE SHEET
BRAZE
WELD NUGGET
BRAZE

(d) WELD-BRAZED JOINT (10 X)

(e) WELD NUGGET-BRAZE INTERFACE (400 X)

Figure 38.- Weld-brazing of titanium structural component.

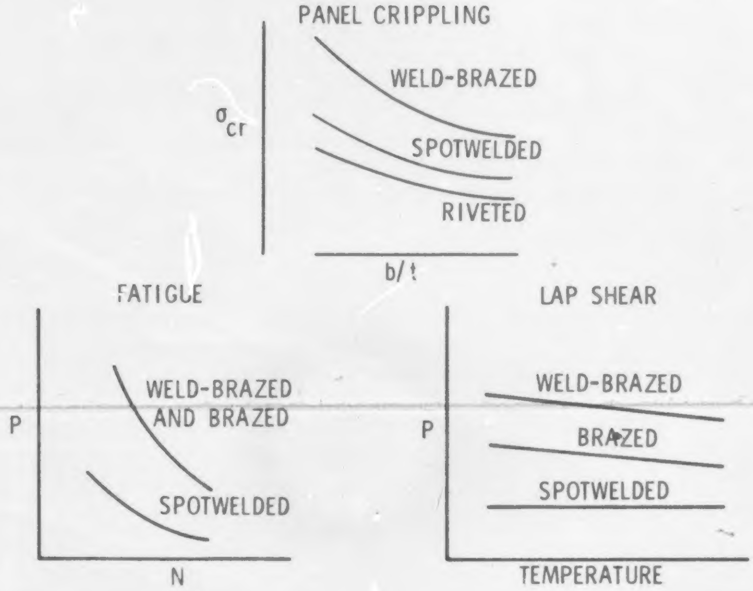


Figure 39.- Comparison of properties of weld-brazed and conventional joints.

STATUS AND TRENDS IN ACTIVE CONTROL TECHNOLOGY

By Herman A. Rediess and Kenneth J. Szalai
NASA Flight Research Center

SUMMARY

The emergence of highly reliable fly-by-wire flight control systems makes it possible to consider a strong reliance on automatic control systems in the design optimization of future aircraft. This design philosophy has been referred to as the control configured vehicle approach or the application of active control technology. Several studies and flight tests sponsored by the Air Force and NASA have demonstrated the potential benefits of control configured vehicles and active control technology.

This paper reviews the present status and trends in active control technology and attempts to predict the impact it will have on aircraft designs, design techniques, and the designer.

INTRODUCTION

Until recent years, aircraft were designed with minimum dependence on augmented flight control systems. Such systems were used only to correct deficiencies, such as excessive hinge moments or low stability, that could not be corrected through conventional aerodynamic balancing or configuration changes. Flight control technology has advanced over the past two decades to the point where augmented systems are now vital to virtually all high performance aircraft.

We are on the threshold of an era in which control systems will be the central element in optimizing aircraft designs to meet their mission and performance objectives. The key ingredient for the stronger role of flight control systems in aircraft design is the development of highly reliable fly-by-wire systems. Three major flight test programs have been conducted recently that demonstrate the feasibility of using pure fly-by-wire flight control systems (systems without a mechanical backup capability): the Air Force Flight Dynamics Laboratory's F-4 survivable flight control system program, the NASA F-8 digital fly-by-wire program (ref. 1), and the Air Force YF-16 lightweight fighter program, which is the first prototype aircraft with a pure fly-by-wire control system.

When fly-by-wire control systems prove to be reliable, practical, and cost effective, they will be applied to many operational aircraft, and the systems can be expected to perform a variety of other flight-critical functions.

Active control technology refers to a class of functions that can be performed by control systems to enhance an aircraft's design. If flight control specialists as well as aerodynamics, structures, and propulsion specialists are involved in the preliminary design process, the synergistic effect of an integrated design can be exploited to an extent not previously possible. This design philosophy has been referred to as the control configured vehicle approach (ref. 2) or the application of active control technology Several studies and flight tests sponsored by the Air Force and NASA have demonstrated the potential payoffs of control configured vehicles and the application of active control technology. The results of many of these studies were presented during a NASA-sponsored symposium in July of 1974 that was entitled "Advanced Control Technology and its Potential for Future Transport Aircraft"; much of the material herein is drawn from this symposium.

This paper reviews the status of active control technology, projects current trends into the future, and makes an assessment of the probable impact of active control technology on aircraft designs, design techniques, and designers. A bibliography on active controls, organized by subtopic, is included.

ACTIVE CONTROL TECHNOLOGY

In a conventional aircraft design process (fig. 1), tradeoffs are made in aerodynamics, structures, and propulsion to meet the mission requirements. Penalties and degradation are often incurred in one area to achieve performance benefits in another; for example, the weight and drag penalties of large tail surfaces may be accepted to achieve positive aerodynamic stability. Once all the compromises have been made that lead to the definition of an aircraft configuration, the vehicle's subsystems are designed, the flight control system among them. Although vital to the successful completion of an aircraft mission, the primary function of a flight control system is to assist the pilot in flightpath control.

In the design of an aircraft by the active control approach (fig. 2), the capabilities of a full-time, full-authority fly-by-wire control system are considered during the preliminary design of the aircraft. Tradeoffs are still made, but it is possible to relax the constraints in the aerodynamics, structures, and propulsion system areas and to rely on the control system to provide the same effective margins artificially. For example, it would be possible to reduce the aerodynamic stability of the aircraft to neutral or even negative to gain a performance advantage and rely on the control system to stabilize the aircraft artificially.

This approach has been used for many years in missile design. In applying the approach to manned aircraft, it should be noted that the control system performs a much more important role than in missiles. Since the system must operate properly for safe flight, it must be highly reliable and capable of full-time operation. This is partly because the system would perform many functions that the pilot would be incapable of performing directly. In these respects, the requirements for an active control system are similar to the requirements for a digital fly-by-wire control system.

The functions that can be classified as belonging to active control technology include handling qualities improvement, flight envelope limiting, relaxed static stability, maneuver load control, direct side force control, ride improvement, gust loads alleviation, flutter mode control, and integrated propulsion system/airframe control.

The current status of and trends in the technology of each of these areas are discussed in subsequent sections. Not all these functions need to be mechanized in a given airplane design; rather, they should be considered in the preliminary design phase and implemented only if the particular function results in a net improvement in the aircraft in terms of its design goals.

A study was made recently to determine whether the performance of a JetStar airplane could be improved by a redesign incorporating active control technology. (The study is discussed in the paper prepared by R. H. Lange and D. A. Deets for the active control technology symposium mentioned previously). The design objectives were to minimize fuel consumption while maintaining or improving the airplane's long range cruise speed, range, payload, and ride and handling qualities. The redesign was limited to the wing and empennage, and a full-time digital fly-by-wire system was assumed to be available. The results of other advances in technology, like supercritical aerodynamics, could be incorporated in the design if they would be available by the 1980's.

The results of the study are summarized in figure 3. The figure shows the basic JetStar airplane, an intermediate design with a supercritical wing but without active controls, and a design with a supercritical wing and a fly-by-wire system for the active control functions. The design incorporating active controls would require 27 percent less fuel than the basic JetStar airplane and approximately 20 percent less fuel than the design using a supercritical wing alone. The active control functions that allowed such large reductions in fuel consumption are gust loads alleviation, ride improvement, and relaxed static stability. The actual performance gain was obtained by going to an unswept wing of high aspect ratio. Without active control functions, this configuration could not have met the ride qualities and gust loads requirements without an excessive weight increase. Thus, the aerodynamics of the airplane were optimized by relying on active controls.

This and several other studies show that significant improvements in aircraft design are possible by incorporating active controls; however, the benefits are specific to the configuration and mission requirements. For example, relaxed static stability may result in a large trim drag reduction for a supersonic cruise airplane and little or none for a subsonic design. Each new design must be carefully examined, and the penalties of active controls, such as system complexity and maintainability, must be considered as well as the benefits.

TECHNOLOGY STATUS AND TRENDS

The various systems and functions that make up active control technology are developing at different rates, so active control systems are at different stages of readiness for military and commercial application. This section describes their current status and probable future applications.

Digital Fly-By-Wire Flight Control Systems

We are on the first rung of the ladder with digital fly-by-wire technology. An important element in the development of this technology is the NASA F-8 digital fly-by-wire flight test program (ref. 1). Figure 4 compares the current status of digital fly-by-wire technology with its status in 1971, when the NASA program was initiated. The first phase of the program demonstrated the feasibility of digital fly-by-wire control systems and validated digital design methods.

One advantage of digital as compared with analog systems is the flexibility provided by the computer software. However, with flexibility comes the need to make sure that the software is correct. Software verification was costly and time-consuming in the Apollo program and was again in the F-8 digital fly-by-wire program (ref. 3). At the present time there is only a medium confidence level that the use of the software flexibility can be made practical.

Two areas of great concern to aircraft users, especially the airlines, are the reliability and maintainability of digital fly-by-wire control systems. The confidence level in these areas is low, as it was in 1971. Figure 5 indicates what is needed to achieve adequate reliability. The useful lifetime of a jet airliner is something over 30,000 flight hours. A single airborne digital computer cannot be expected to be reliable for this length of time, but it may be possible to achieve a digital fly-by-wire system with the necessary service reliability by making it redundant (using three to four computers). However, the extensive testing that would prove that redundant systems provide adequate reliability has not yet been done.

Although the second phase of the NASA F-8 digital fly-by-wire program and Air Force and Navy research and development programs will answer many technical questions, the reliability and maintainability questions of digital fly-by-wire systems will be adequately addressed only when many systems are in actual military and commercial operation. The application of these systems will probably be evolutionary, starting with non-flight-critical functions and, as confidence is developed, transitioning into flight-critical functions.

The flight control system of the future for commercial airliners may look like that shown in figure 6, which is an advanced guidance and control system being studied by NASA and Boeing (ref. 4). All the navigation, flight control, autopilot, autoland, and associated control and display functions are performed by the system, but the flight-critical and non-flight-critical tasks are separate. The computations required for navigation, automatic cruise, autothrust, and the generation of guidance commands and displays are performed by navigation guidance computers. The flight-critical tasks required for command augmentation, autoland, and overall system integrity are performed by flight control computers. This federated approach provides the necessary redundancy for the performance of every task and minimizes the importance of the equipment involved.

Before complex digital systems can be applied to commercial airliners, however, their dispatch reliability and maintainability must be improved. The use of digital computers together with self-test and diagnostic routines will eventually make the attainment of this goal possible. There is little question that future flight control systems will be digital.

Handling Qualities Improvement

Automatic flight control systems like stability augmentation systems (SAS) and command augmentation systems have been used to improve aircraft handling qualities for many years. Most high performance aircraft, both military and commercial, use some type of stability augmentation system or command augmentation system. The technology for mechanizing such systems is well developed, although there are some deficiencies in the handling qualities criteria needed to design the systems.

The subject is mentioned here for completeness, since the improvement of handling qualities is an important function of active controls and an integral part of fly-by-wire flight control systems.

Flight Envelope Limiting

Flight envelope limiting refers to using active controls to prevent an aircraft from entering some portion of its flight envelope (in terms of, for example, Mach number, angle of attack, or normal acceleration). The limiting is used to prevent the aircraft from getting into a hazardous situation. For example, the YF-16 lightweight fighter prototype is limited in angle of attack and normal acceleration (paper by Charles A. Anderson, active control technology symposium). No matter what the pilot does, the flight-envelope-limiting system prevents the airplane from stalling, and, therefore, from possibly entering a spin or suffering structural damage.

When digital control logic is commonplace in flight control systems, envelope limiting will probably be used to a much greater extent, and it will be more complex in nature. The limiting can be a function of many variables and optimized for each flight condition, airplane configuration, external store arrangement, and mission requirement. A digital computer is well suited to this task.

Relaxed Static Stability

A conventional airplane design has natural aerodynamic static stability, which means that to trim the airplane there must be a download on the horizontal tail. The tail download, in turn, makes greater wing lift necessary and increases the trim drag. By relaxing the requirement for natural static stability and permitting an active control system to provide this stability artifically, trim drag can be reduced and performance improved.

Figures 7 and 8 show the effect that relaxed static stability had on the Boeing supersonic transport design (ref. 5). The design incorporated a highly reliable and simplified stability augmentation system, called hard SAS, that allowed the airplane's static stability to be reduced and the center of gravity to be moved aft by 5 percent. The balance problem was eliminated, and 3.8 meters of the forward fuselage, which were originally required for balance, were eliminated. The size of the vertical tail was reduced, and trim drag decreased significantly. The aggregate effect of these design changes on the airplane's performance is shown in figure 8. Without active controls, the airplane would have been short of its design range by 417 kilometers or its payload would have had to have been reduced by 30 percent. The performance gains were so significant and their cause so clearly defined that the Boeing Company was willing to incorporate the hard SAS in the transport's design.

Relaxed static stability can also improve the cruise and maneuvering performance of fighter airplanes. The YF-16 prototype took advantage of relaxed static stability. Figures 9 and 10 (from Anderson, active control technology symposium) show how relaxed static stability reduces the conventional trim requirement and improves the lift/drag polar. At maneuvering lift coefficients, lift increases approximately 8 percent and 15 percent at subsonic and supersonic Mach numbers, respectively, for a given drag level, which translates directly into higher sustained load factors. Since the YF-16 prototype uses a pure fly-by-wire flight control system, which must function properly for the airplane to fly, there is no increase in risk in incorporating relaxed static stability.

The technology for applying relaxed static stability is at hand and is sure to be used in cases where performance can be improved significantly and the system's reliability can be ensured.

Maneuver Load Control

The basic concept of maneuver load control is illustrated in figure 11, which is adapted from reference 2. The spanwise loading of an efficient wing is approximately elliptical under 1g and maneuvering conditions (labeled conventional control in fig. 11). With maneuver load control, the loading is the same as with conventional control at 1g load conditions, but as load increases in a maneuver, the lift distribution changes and the active control system shifts more of the load to the wing root area. The aerodynamic center is forced to move inboard, which reduces the wing root bending moment. The lower wing bending moment allows the wing's structural weight to be reduced.

The Air Force Flight Dynamics Laboratory recently completed flight tests of a Boeing B-52 control configured vehicle, in which several active control concepts were incorporated, including maneuver load control. The flight test data presented in figure 12 (from J. I. Arnold and F. B. Murphy, active control technology symposium) show a 40-percent reduction in the wing root bending moment per g for an incremental 1g maneuver.

Significant wing root bending moment reductions were also demonstrated in flight tests of an active control system installed in a Lockheed C-5A airplane (W. J. Hargrove, active control technology symposium). The major airplane components of this system, which is called an active lift distribution control system, are shown in figure 13. The reductions achieved in wing root bending moment per g for maneuvering flight are summarized in table 1. The bending moments per g for the airplane with an active control system were 30 percent to 50 percent less than those for an airplane without the system throughout the flight envelope.

Use of maneuver load control and relaxed static stability can result in a lower design gross weight by allowing a lighter wing structure to be used. Figure 14 summarizes the results of a study made to determine the compatibility of maneuver load control and relaxed static stability for bomber and fighter configurations (ref. 6). Significant reductions result with either maneuver load control or relaxed static stability, and if both are used, reductions on the order of 20 percent are possible.

Maneuver load control technology is fairly well understood and can be applied now to a limited extent. The active lift distribution control system tested in the C-5A airplane may be retrofitted into fleet aircraft to improve airframe life. The incorporation in the design of new aircraft of the lighter wing structure made possible by using maneuver load control is still in the future, awaiting proof of adequate system reliability.

Direct Side Force Control

Control over the side forces produced on airplanes is not a natural feature of airplane design. Several simulator studies and two flight test programs with special research aircraft have been conducted to investigate the benefits of such control. Direct side force control has been considered for improving the crosswind controllability of short takeoff and landing aircraft during landing approaches and for improving the air-to-air and air-to-ground tracking capabilities of fighter aircraft. In all the cases studied, direct side force control allowed the airplane to make a sidestep type of maneuver without banking. Direct side force control has also been considered for improving ride qualities in turbulence.

Direct side force control will probably not be considered seriously until more extensive flight testing with research aircraft has been conducted.

Ride Improvement Systems

An uncomfortable ride during flight through turbulence results from the rigid response of the airplane and the excitation of the airplane's structural modes. For small aircraft with light wing loading, a rough ride is due primarily to airplane rigid response. For larger, more flexible aircraft, both factors are involved, but the primary source of discomfort is the excitation of the structural modes. The active control approach to improving ride qualities differs for each case.

A feasibility study of a ride improvement system for a short takeoff and landing aircraft with light wing loading (the DHC-6 airplane) was performed by the Boeing Company under contract to NASA (ref. 7). The airplane's configuration and the surfaces used in the active control system are shown in figure 15. The split ailerons were used as flaperons and they and the spoilers provided direct lift control. The vertical ride control system used pitch rate and normal acceleration feedbacks, and the lateral ride control system used yaw rate and lateral acceleration feedbacks. (High vertical and lateral accelerations are major contributors to poor ride quality). Figure 16 shows the effectiveness of the DHC-6 ride improvement system in reducing these accelerations. The largest improvement was in the reduction of vertical motion. Direct side force control would be needed to obtain a similar improvement in lateral motion. A ride improvement system like this one could greatly enhance passenger acceptance of small commuter aircraft and of short takeoff and landing aircraft with light wing loading.

Several studies and flight test programs have investigated ride improvement systems for large, flexible aircraft. Two systems worthy of note are the Rockwell B-1 structural mode control system (ref. 8) and the Boeing B-747 lateral ride improvement system (G. C. Cohen, C. J. Cotter, D. L. Taylor, and D. Leth, active control technology symposium). The objective of the B-1 system is to reduce the crew fatigue due to long periods of flight in turbulence. The system suppresses both vertical and lateral motion at the cockpit through a set of canards that can be deflected collectively for vertical control and differentially for lateral control. This system will be flight tested in 1975.

A system intended to improve the lateral ride qualities in the aft end of the Boeing B-747 has been built, flight tested, and certified for airline operation. The system has tow parts, one of which operates the lower segment of the rudder and the other the upper segment of the rudder. The first system suppresses the structural modes, and the second system reduces the lateral acceleration of the Dutch roll frequency. The flight test data for these systems show a 50-percent to 70-percent reduction in rms lateral aft body acceleration levels.

Since ride improvement systems are not flight critical or even dispatch critical, their use does not depend on the development of highly reliable flight control systems, and therefore they should come into service earlier than other active control functions. Competition in the commercial field will undoubtedly promote the use of these systems. Once one airline adopts them and the public experiences its transports' smoother ride, the other airlines will have to use them too.

The design technology for structural mode control systems is inadequate because an airplane's structural dynamic characteristics cannot now be predicted accurately. At the present time, an airplane's structural dynamic characteristics must be measured in flight for an effective structural mode control system to be designed (Cohen et al., active control technology symposium).

Gust Loads Alleviation

Gust loads are important in aircraft design, from the standpoint of both the maximum bending moments they can induce on a wing and the fatigue life of the entire aircraft. Active control systems designed to reduce gust loads have been given a variety of names, such as gust loads alleviation, loads alleviation and mode suppression, and fatigue reduction and structural mode control. Probably the most important system to date is the stability augmentation system that was installed on a B-52 airplane, which was of the loads alleviation and mode suppression type (ref. 9). That system utilized the control system to reduce the aircraft's acceleration response to turbulence at its primary bending mode frequencies, reducing fatigue damage. Flight test results showed that the aircraft with the system could fly 11 times longer than an aircraft without it before the same fatigue damage for a low altitude, high speed penetration condition was incurred. This led the Air Force to retrofit the entire B-52 G and H fleet, which consisted of nearly 300 airplanes, with a similar load alleviation system.

The C-5A active lift distribution control system discussed under maneuver load control also alleviated gust loads. Figure 17 presents flight test data for the ratio of the system-on to the system-off wing root rms bending moments over a range of Mach numbers and altitudes. The bending moments were reduced 30 percent to 50 percent by the active lift distribution control system. The wing root rms torsion moments (fig. 18) were also measured. There was some concern that the active lift distribution control system might increase the torsion moments because of the swept wings and the resulting force at the trailing edge of the wing near the tip. Figure 18 shows that in general the torsion moments were also reduced slightly, except at an altitude of 457 meters, where they were slightly higher than in the basic airplane.

The increase in torsional moments at one flight condition brings out an important aspect of applying active control concepts. The penalties, as well as the benefits, of any particular active control function must be assessed. Unfortunately, some penalties may not surface until flight tests are made.

Some aircraft are being retrofitted with gust loads alleviation systems, which are not flight critical. It has been used to a limited extent in a new design in that the L-1011 yaw damper reduces vertical tail loads by approximately 20 percent (ref. 10). However, a full application of gust loads alleviation, which would allow lighter structures to be used, has not yet been made. Such applications will require the same reliability as pure fly-by-wire systems and are paced by the development of that technology.

The design of systems for gust loads alleviation, like systems for structural mode control, suffer from deficiencies in the technology of structural dynamics modeling.

Flutter Mode Control

Flutter can be suppressed by using a control system that damps a critical flutter mode artificially. Flutter mode control can allow the wing structure to be lighter as long as the determining factor in the strength and stiffness of the wing's design is not ground operation or landing loads.

The flight tests of the control configured B-52 airplane proved the feasibility of flutter mode control (Arnold and Murphy, active control technology symposium). Figure 19 shows the configuration of this airplane, which incorporates new outboard ailerons, flaperons, and 8896 newtons of ballast in the external tanks. The ballast was used to create an unstable flutter mode within the normal flight envelope. The flight test data in figure 20 show that flutter mode control provided adequate damping up to the maximum speed tested, which was 5.1 meters per second greater than the predicted flutter speed.

The design process for the flutter mode control system for the B-52 airplane was unique in that a good structural dynamics model of that particular B-52 airplane already existed from the extensive testing done for the loads alleviation and mode suppression program. In addition, the system was designed for only one flight condition. To design an effective flutter mode control system, a good structural dynamics and unsteady aerodynamics model is necessary for all the flight conditions at which the flutter mode control system is to operate. The technology is a long way from having models accurate enough to design a flutter mode control system that can operate, as it must, from the first flight of a new aircraft. Since flutter is an explosive type of instability and can therefore cause catastrophic structural damage in seconds, it is just as important for the design of the flutter mode control system to be correct as it is for the hardware to function. The development of flutter mode control probably has the farthest to go of all active control concepts.

Integrated Propulsion System/Airframe Control

Supersonic cruise aircraft can exhibit strong interactions between the propulsion system and the airframe. These interactions can be aggravated or improved by the behavior of the propulsion control system and the flight control system. When these controls are designed independently, they tend to affect the interactions adversely. When the propulsion and flight controls are integrated, however, the benefits can be synergistic. This is a relatively new area to be thought of as active control technology, but it certainly fits the definition.

Various airframe/propulsion system interactions have been shown to significantly affect aircraft performance, stability, and control (D. T. Berry and W. G. Schweikhard, active control technology symposium). Changes in drag as large as 25 percent (per engine) of the total drag can be involved. Forces and moments as powerful as those produced by the aerodynamic controls have been observed. If not accounted for, these effects can lead to large performance degradations, large flightpath excursions, and increased pilot workload.

Cooperative or integrated operation of the propulsion and flight controls (fig. 21, from Berry and Schweikhard, active control technology symposium) may provide a solution to these problems. Control integration has the potential not only to eliminate the adverse effects of the interactions but, through synergistic effects, to improve aircraft performance. The benefits of propulsion/flight control system integration include lower airframe weight, improved flightpath control, greater overall system simplicity, and more efficient operating limits. The performance gains that may be realized by using an integrated control system in future supersonic cruise aircraft are summarized in table 2. Although it may be that the gains listed are not directly additive, the total represents approximately 7 percent of the gross weight of a typical supersonic airplane. This is approximately the same as the payload of a supersonic transport.

Analytical and flight research programs are underway at NASA to investigate the benefits of an integrated control system in an operational environment using a YF-12 airplane. Considerably more effort will be necessary before the potential of these systems is realized.

Future Trends

The first digital flight control system (not a pure fly-by-wire system) intended for an operational fixed-wing airplane in the United States is being developed for the Boeing YC-14 short takeoff and landing transport, which is scheduled for flight testing in 1976. Digital flight control will probably not be used commercially until the middle to late 1980's, when a new round of transports is developed. At that time digital fly-by-wire control systems should also be considered for military applications. Pure fly-by-wire systems will probably not be considered seriously for commercial application until substantial military experience has been acquired with them, possibly in the 1990's.

Flight envelope limiting is being used on the YF-16 airplane and will continue to be used by the military. Application to commercial aircraft has yet to be considered.

Relaxed static stability will continue to be used whenever the performance benefits are substantial and if the airplane can at least be landed if the system fails (as in the design for the Boeing supersonic transport). The commercial transports developed in the 1980's may use relaxed static stability to a limited extent. Total reliance on the flight control system for static stability will not occur until fly-by-wire technology is firmly established, probably in the 1990's.

Commercial transports may start to use maneuver load control early in the 1980's in growth versions of existing aircraft, to allow, for example, increased payloads for cargo airplanes. Maneuver load control will probably not be used fully until the late 1980's or early 1990's.

Direct side force control technology should be ready for the development of new fighter aircraft in the late 1980's. The short takeoff and landing aircraft of the 1990's may use some form of direct side force control. The development of this technology will probably not have high priority.

Ride improvement systems are here now, for both military and commercial applications. The use of such systems is expected to increase steadily through the years.

Gust loads alleviation systems are being used now to a limited extent, but they will probably not replace structural stiffness until about 1990.

The greatest uncertainty exists in predicting when flutter mode control systems will be relied on in ordinary flight operations. Limited applications may be made in the 1980's for off-design conditions, such as overspeed conditions. Applications will probably be few until the 1990's. System reliability and design techniques are the delaying factors.

The technology for a completely integrated propulsion, autopilot, and stability augmentation system should be ready in the 1990's, when the United States may reconsider building a supersonic transport. More attention will probably be paid to the interaction of these systems, and limited design trades will be made among the disciplines in the meantime.

Acceptance of active control technology as a design philosophy will be slow in coming. Some people claim to have been using an active control design approach for years, but most active control advocates question that. There have been several applications of active control technology, but they were not included in the design until it became clear that there was no other effective way to meet the design requirements. Active controls were incorporated in the design of the YF-16 lightweight fighter prototype only because this program was intended to foster advances in technology. The success of the program should help considerably to promote fly-by-wire systems and active controls. The design philosophy of a company is, as it should be, guided by the chief design engineers, and they are not now convinced that active controls will result in a new gain when all the factors, technical and nontechnical, involved in the success of a design are considered.

An active control design philosophy cannot be developed fully until fly-by-wire flight control systems are completely accepted, and that will probably occur in the 1990's. Once fly-by-wire systems have been proven reliable, maintainable, and most important, cost effective, they will be used, and the use of active controls will follow naturally.

IMPACT OF ACTIVE CONTROL TECHNOLOGY ON AERONAUTICS

Active control technology will have a tremendous impact on aeronautics over the next 20 years. It will affect not only the design of future aircraft but also the design techniques and the designer himself.

Impact on Future Aircraft Designs

NASA sponsored three advanced transport technology studies by Boeing, General Dynamics/Convair, and Lockheed. Assessments were made of the technology in single disciplinary areas such as supercritical wing technology and composite structures. The interdisciplinary application of active control technology was also considered. The potential benefits of incorporating several active control functions in an aluminum, sonic transport arc shown in figure 22 (from Ray V. Hood, active control technology symposium) in terms of incremental return on investment and the resulting incremental profit per year, based on a fleet of 280 airplanes. The measurement of absolute economic advantage is subject to the usual uncertainty in the present economic models used by air transport industry, but the results show that substantial gains are possible. The physical difference between a conventional design and an active control design for one study is shown in figure 23.

The advanced transport technology studies did not consider a true active control design but rather an active control version of an existing design. A total commitment to an active control design is expected to result in benefits in performance and economy that are more dramatic. The benefits of a pure active control design, in which several active control concepts were employed simultaneously, were explored in an Air Force-sponsored design exercise with Boeing (Stephen A. Walker, active control technology smyposium). Two preliminary designs were made for a tanker aircraft. The aircraft had a refueling mission and had to offload a 1,552,352-newton payload. Using normal design procedures, a fairly conventional aircraft configuration was obtained. A substantially different configuration resulted when five active control concepts were incorporated. The two configurations are compared in figure 24. The active control tanker had no horizontal tail and had a takeoff gross weight 16 percent less and an empty weight 25 percent less than the conventionally designed aircraft. It had the same payload range capability and would have performed the same mission.

The intent of active control technology is not to come up with novel designs, but rather to improve aircraft performance and economy. Boeing estimated that the active control tanker would cost 20 percent less than a conventional airplane for a fleet of 100 aircraft. An equally important aspect of the cost saving was that the fuel consumption of the active control tanker was approximately 25 percent less than that of the conventional airplane. This factor has obvious impact far beyond military transport aircraft.

Other aircraft design studies are needed so that the benefits and penalties of active controls can be fairly assessed. The studies need to be in much greater depth and detail than in the past. If the net benefits are as substantial as present studies indicate, active controls will have great impact on aeronautics in the future.

Impact on Design Techniques

Active control technology is by its very nature involved in the interaction of disciplines - propulsion systems, control, aerodynamics, and structures - so the techniques used to design active control systems must also be interdisciplinary. The techniques must also allow studies to be made rapidly and accurately. Designers cannot wait from 9 months to a year per iteration going from selecting an aerodynamic configuration to defining the structural loads to developing a structural model to designing the control system, as is often the case now. Analytical techniques are needed that accurately predict structural dynamic characteristics and, in particular, flutter dynamics, including unsteady aerodynamics. Figure 25 shows how far off analytical predictions of flutter can be (R. V. Doggett, I. Abel, and C. L. Rohlin, active control technology symposium).

The obvious trend is that digital computer programs will be relied upon more and more to assist in analyzing design options. Computational aerodynamics and structural dynamics will also be important in the active control design process. The computer will not replace the design engineer, but it will greatly expand his design options and reduce the time for each design iteration.

Impact on the Designer

The designer will have to be skilled in several disciplines. He must not emphasize any discipline, even the control system, to the detrement of the overall design. He must know how to use and not abuse computer analysis.

Engineering schools should start now to develop courses in interdisciplinary aeronautical engineering. If possible, instruction should be given in computer-aided design methods. A cooperative effort will be needed between the government, industry, and the universities to make computer programs and techniques available to the universities.

CONCLUDING REMARKS

Active control technology is at the beginning of its development and is expected to have great impact on aeronautics in the future. The various active control concepts, such as digital fly-by-wire systems, relaxed static stability, maneuver load control, ride improvement systems, gust loads alleviation, and flutter mode control have all been proven feasible through flight test programs and should come into service over the next 10 to 15 years. The complete acceptance of the active control design philosophy probably hinges on the complete acceptance of fly-by-wire systems, which is not expected until the 1990's.

Active control technology should result in substantial benefits to new aircraft designs. To achieve this, the design techniques and designers of the future must have an interdisciplinary approach, and they will have to rely more heavily on computer-aided design and analysis.

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TABLE 1.– REDUCTION IN WING ROOT BENDING MOMENT DUE TO ACTIVE LIFT DISTRIBUTION CONTROL SYSTEM IN C-5A AIRPLANE

Weight				
Cargo, N	Fuel, N	Velocity, m/sec	Altitude, m	Bending moment/g with active controls / Bending moment/g without active controls
711,680	419,224	136	9,144	0.64
711,680	954,096	134	2,286	0.57
0	419,224	175	6,096	0.49
711,680	202,829	180	SL	0.70
711,680	419,224	113	3,048	0.56
845,120	41,366	113	3,048	0.60
711,680	419,224	139	SL	0.55
845,120	41,366	170	7,620	0.65

TABLE 2.– ESTIMATED PERFORMANCE GAINS FOR A SUPERSONIC CRUISE AIRPLANE WITH AN INTEGRATED CONTROL SYSTEM

	Payload gain, percent of airplane gross weight
Margin reduction –	
Inlet stability	1.8
Engine temperature	2.0
Altitude control	1.0
Drag reduction –	
Propulsion system	1.2
Trim	0.7
Structural weight reduction –	
Ventral fin	0.4
Total (if additive)	7.1

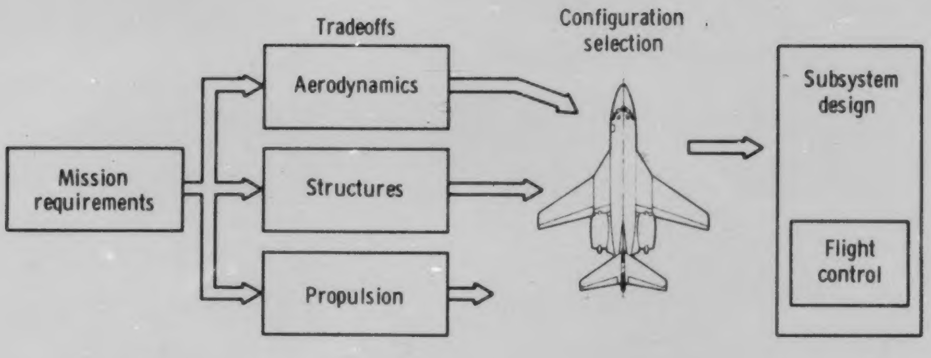
Tradeoffs
Configuration selection
Aerodynamics
Mission requirements
Structures
Propulsion
Subsystem design
Flight control

Figure 1.- Conventional aircraft design procedure.

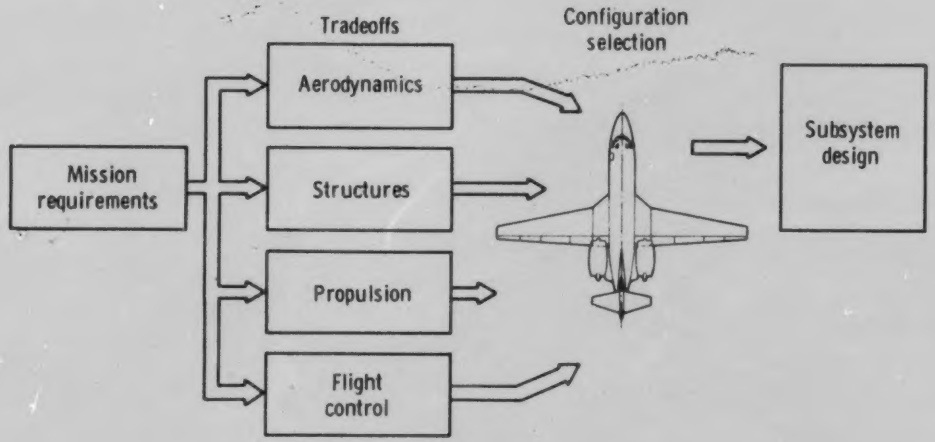
Tradeoffs
Configuration selection
Aerodynamics
Mission requirements
Structures
Propulsion
Flight control
Subsystem design

Figure 2.- Active control technology design approach.

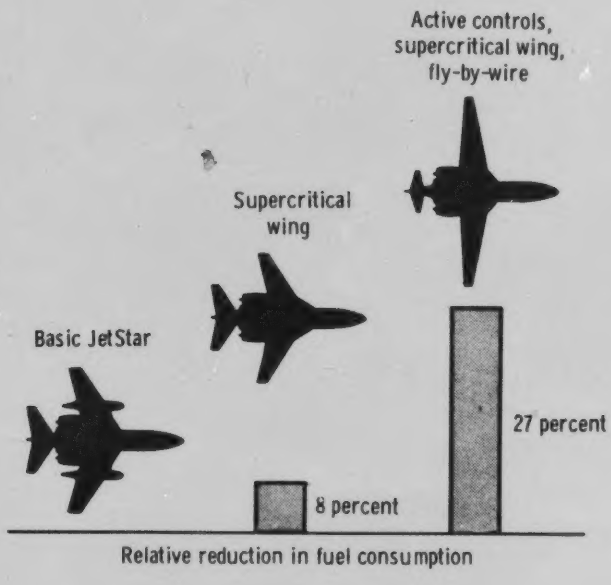

Figure 3.- Potential benefits of applying active control technology.

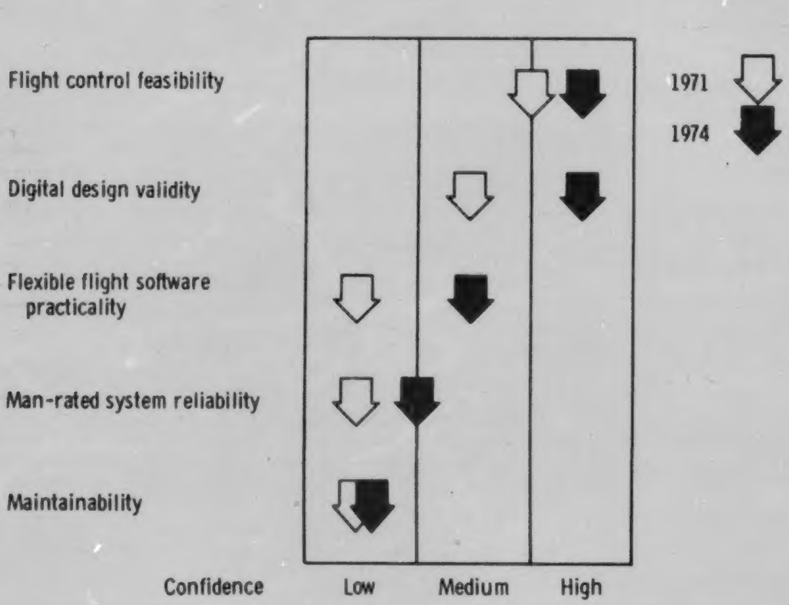

Figure 4.- Confidence in digital fly-by-wire technology.

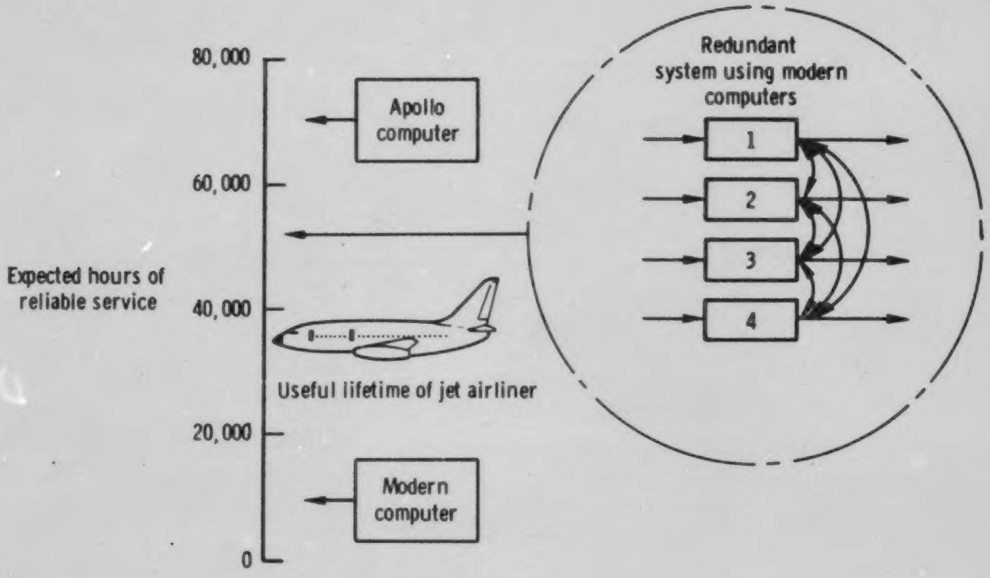
80,000
60,000
40,000
20,000
0
Expected hours of reliable service
Apollo computer
Modern computer
Useful lifetime of jet airliner
Redundant system using modern computers
1
2
3
4

Figure 5.- Requirements for digital fly-by-wire system service.

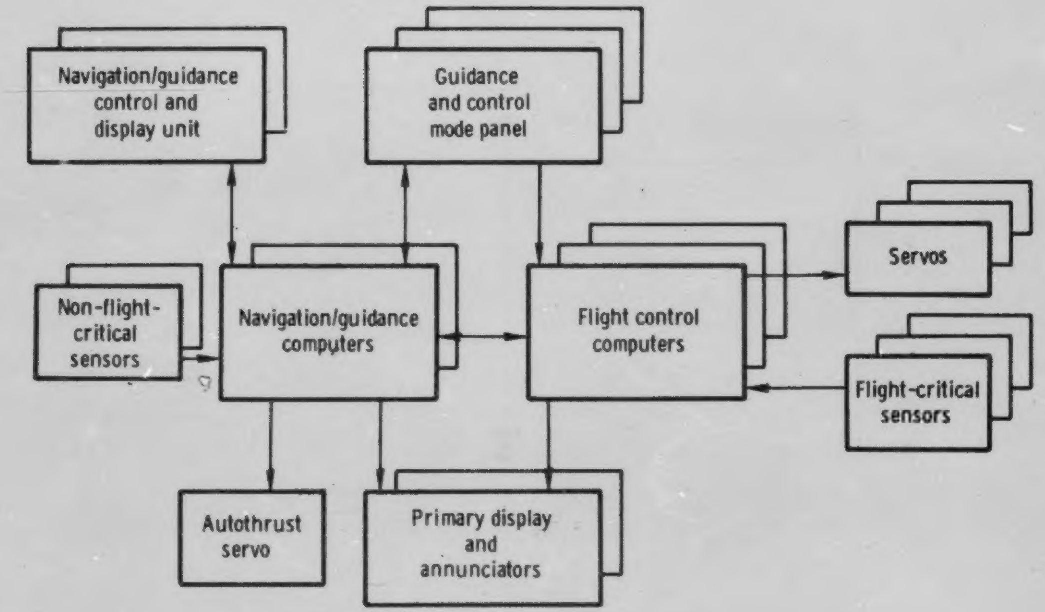
Navigation/guidance control and display unit
Guidance and control mode panel
Non-flight-critical sensors
Navigation/guidance computers
Flight control computers
Servos
Flight-critical sensors
Autothrust servo
Primary display and annunciators

Figure 6.- Conception of an advanced guidance and control system (ref. 4).

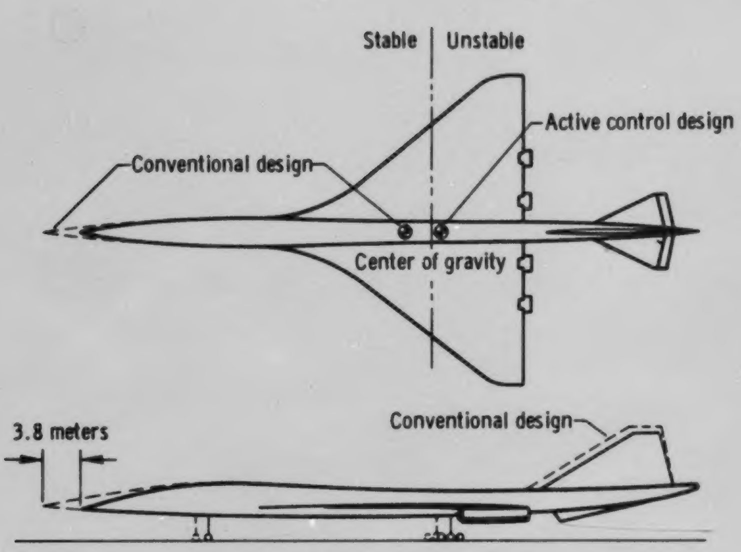
Stable
Unstable
Active control design
Conventional design
Center of gravity
3.8 meters
Conventional design

Figure 7.- Effect of relaxed static stability on a supersonic transport configuration (ref. 5).

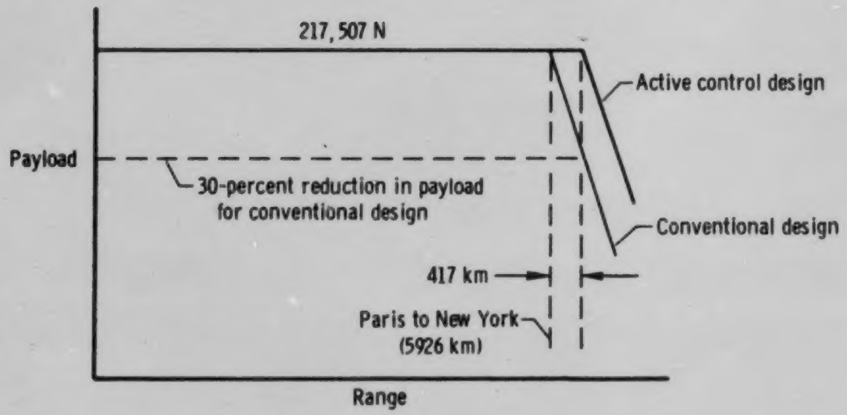

Figure 8.- Effect of relaxed static stability on the payload and range of a supersonic transport design (ref. 5).

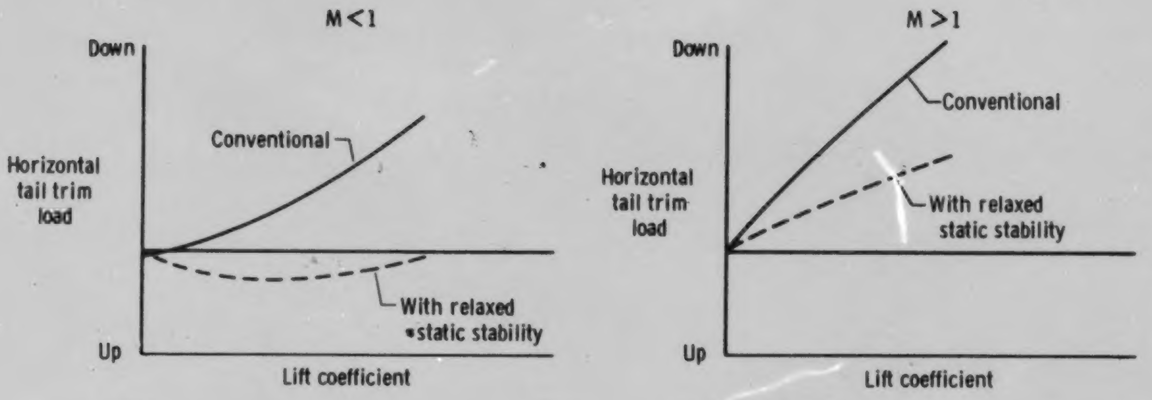

Figure 9.- Effect of relaxed static stability on the trim stabilizer deflection for a fighter airplane.

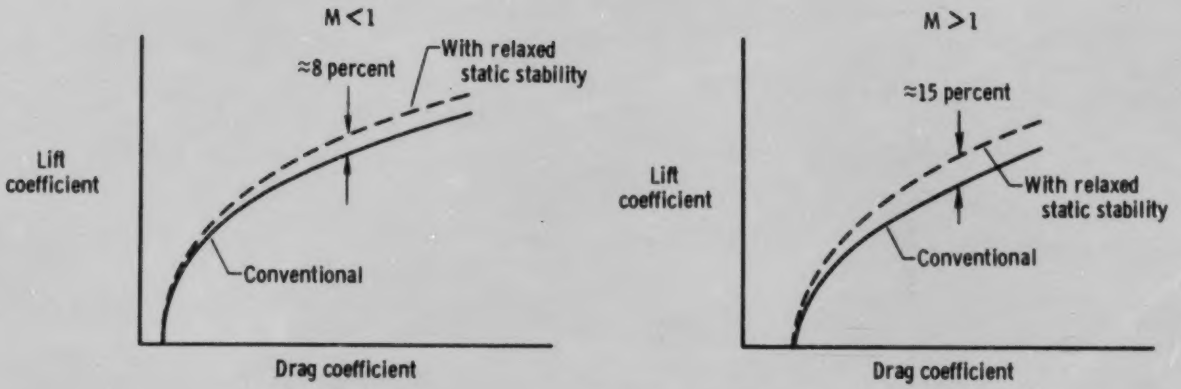

Figure 10.- Effect of relaxed static stability on the lift/drag polar for a fighter airplane.

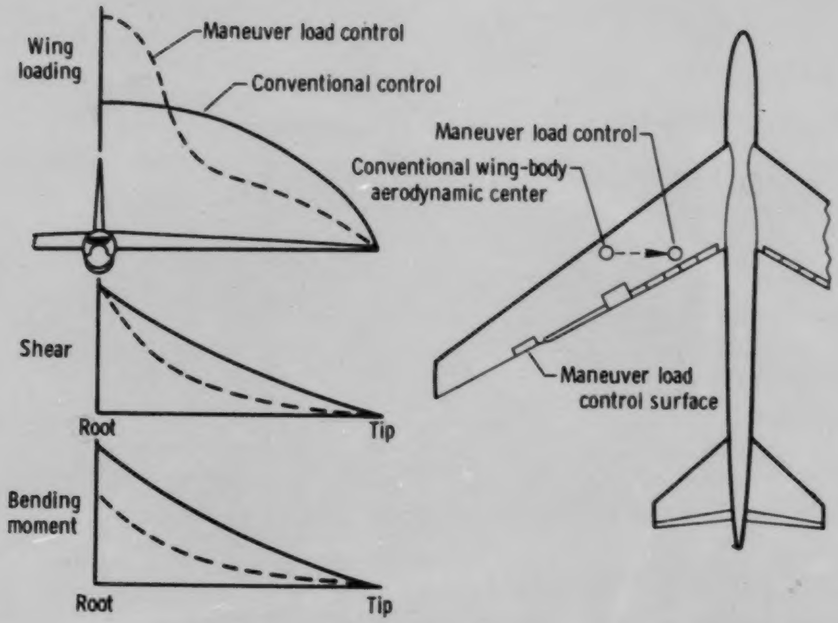
Wing loading
Maneuver load control
Conventional control
Shear
Root
Tip
Bending moment
Root
Tip
Maneuver load control
Conventional wing-body aerodynamic center
Maneuver load control surface

Figure 11.- Maneuver load control concept for the B-52 control configured airplane (adapted from ref. 2).

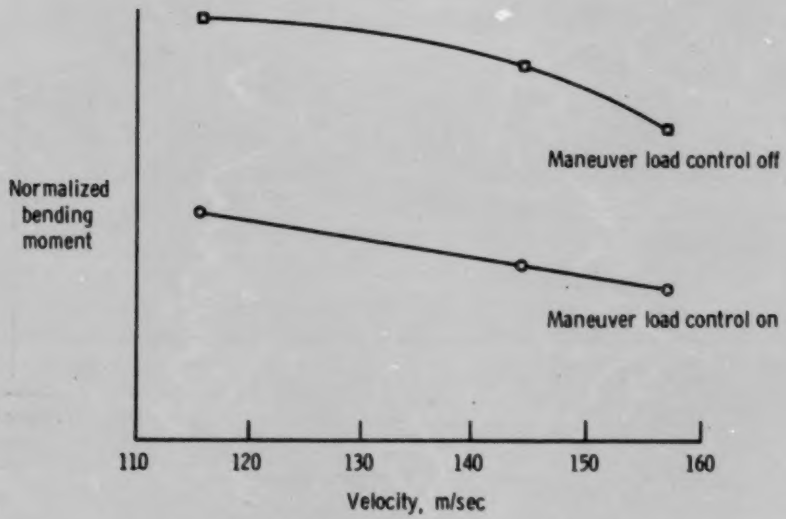

Figure 12.- Wing root vertical bending moment reduction versus airspeed for the B-52 control configured airplane.

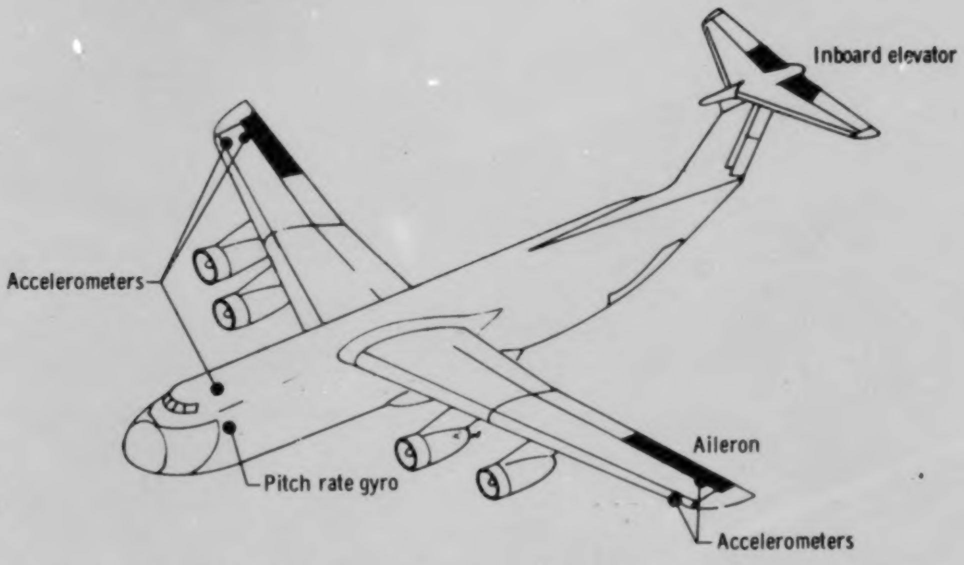
Inboard elevator
Accelerometers
Aileron
Pitch rate gyro
Accelerometers

Figure 13.- Major airplane components of the C-5A active lift distribution control system.

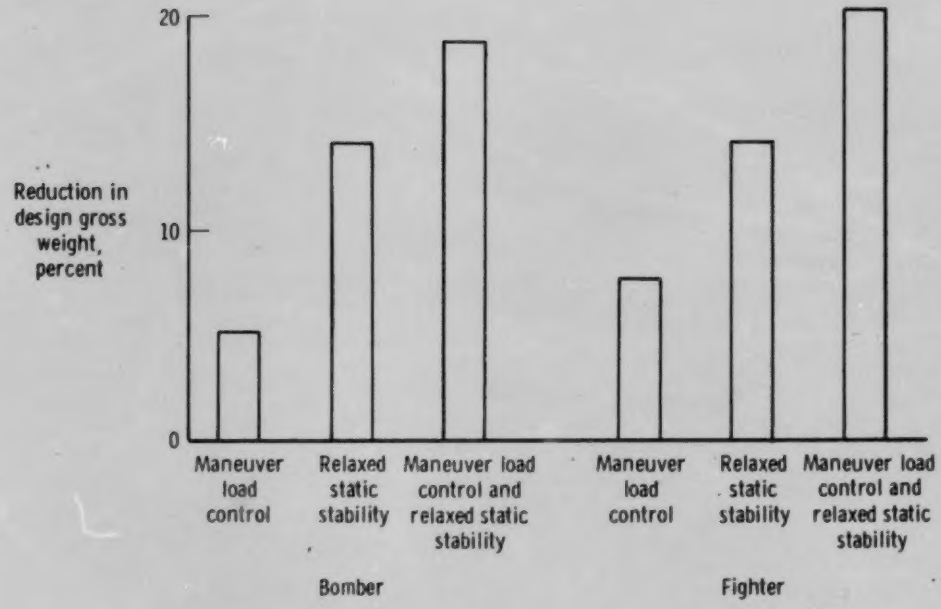

Figure 14.- Reduction in design gross weight due to application of maneuver load control and relaxed static stability for a bomber and a fighter aircraft (ref. 6).

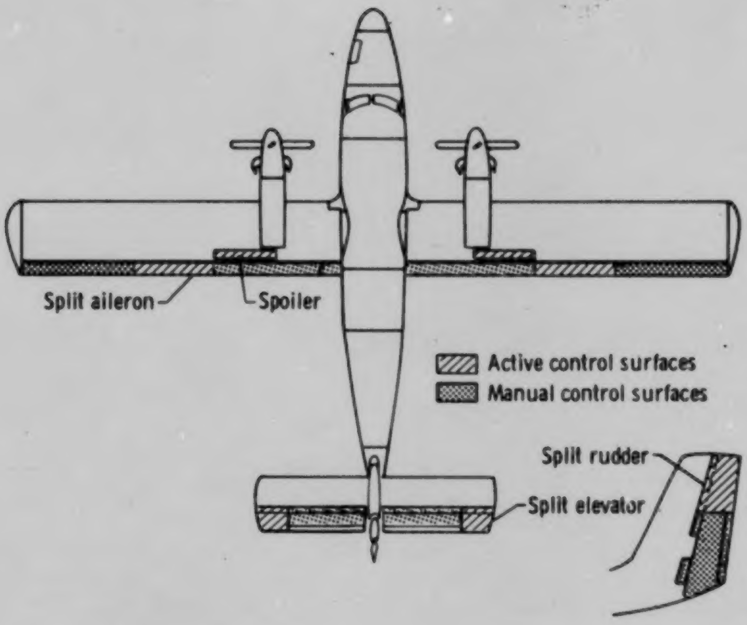
Split aileron
Spoiler
Active control surfaces
Manual control surfaces
Split rudder
Split elevator

Figure 15.- Active control surfaces studied on DHC-6 aircraft (ref. 7).

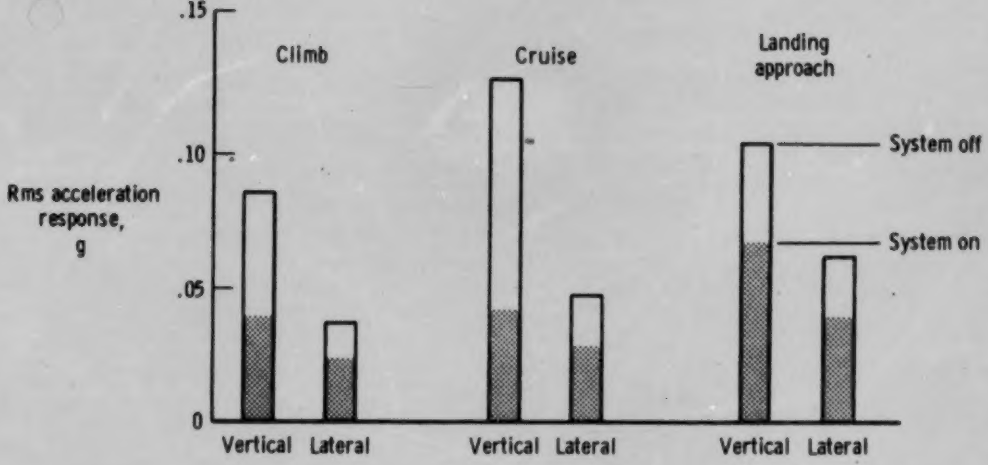

Figure 16.- Effectiveness of the DHC-6 aircraft ride control system in terms of aft cabin response to 2.1-meter-per-second gusts (ref. 7).

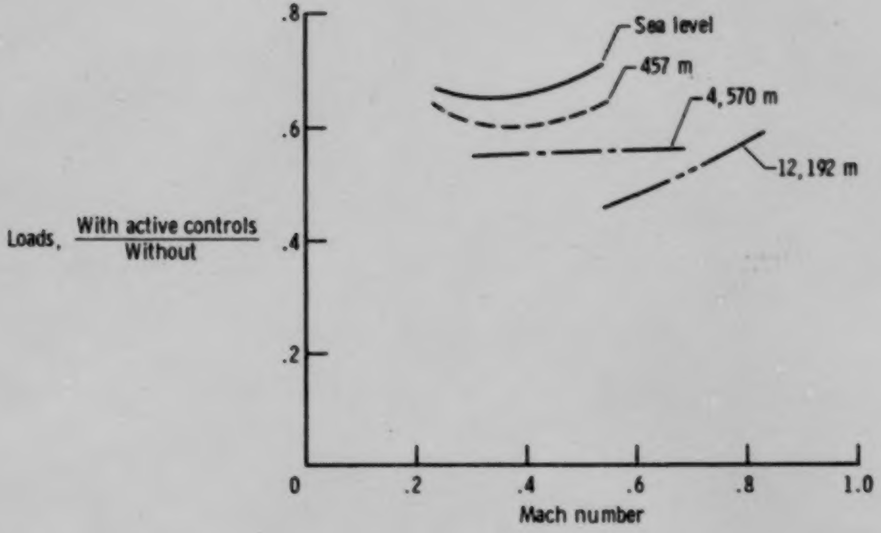

Figure 17.- The C-5A active lift distribution control system wing root rms bending moment ratio.

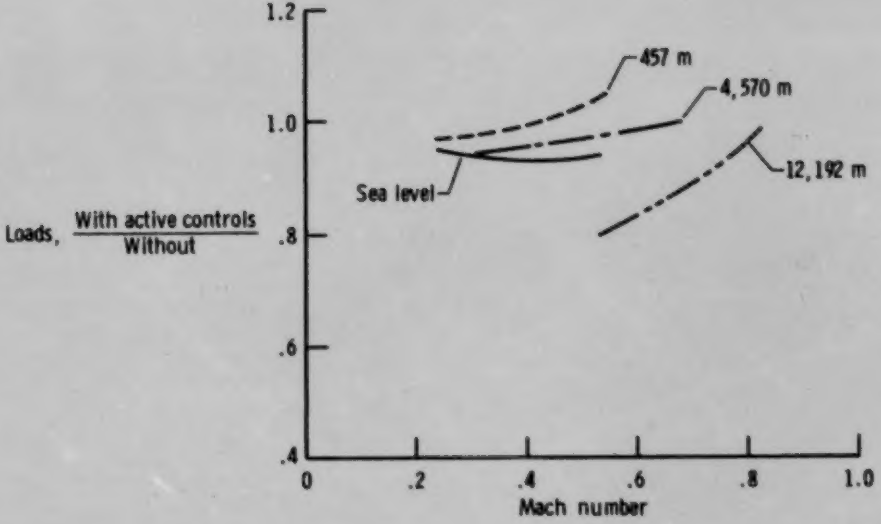

Figure 18.- The C-5A active lift distribution control system wing root rms torsion moment ratio.

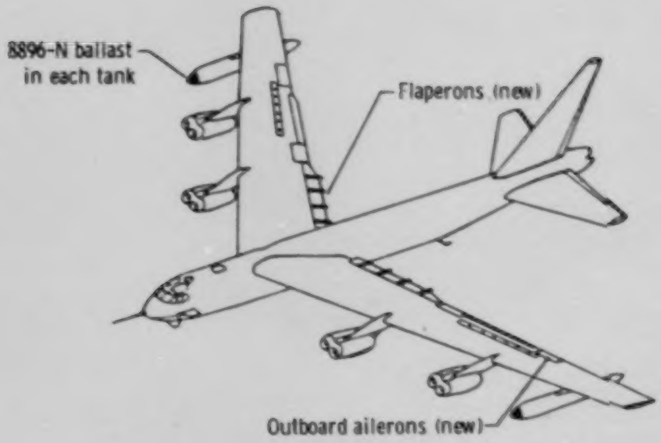
8896-N ballast in each tank
Flaperons (new)
Outboard ailerons (new)

Figure 19.- Flutter mode control configuration of the B-52 control configured airplane.

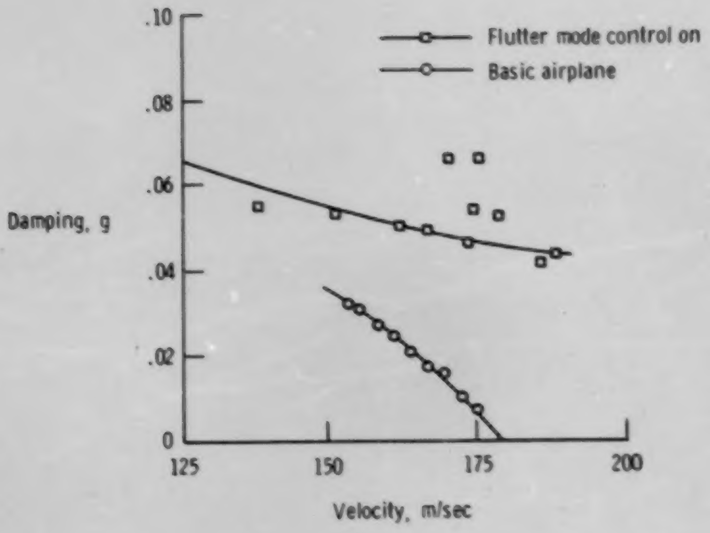

Figure 20.- Flight test flutter results on the B-52 control configured airplane.

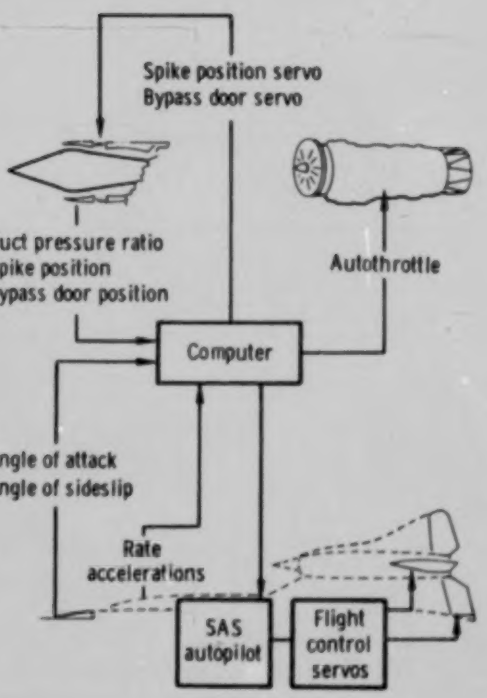
Spike position servo
Bypass door servo
Duct pressure ratio
Spike position
Bypass door position
Autothrottle
Computer
Angle of attack
Angle of sideslip
Rate
accelerations
SAS
autopilot
Flight
control
servos

Figure 21.- Integrated autopilot/stability augmentation/propulsion control system proposed for a YF-12 airplane.

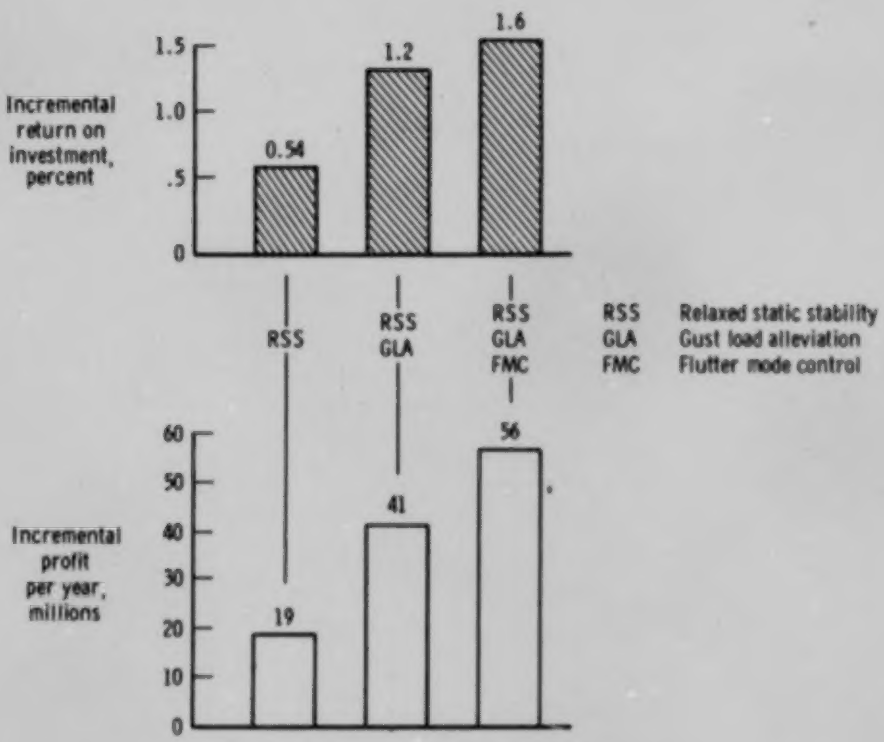

Figure 22.- Estimated economy of applying active controls to a fleet of advanced sonic transports, assuming a fleet size of 280.

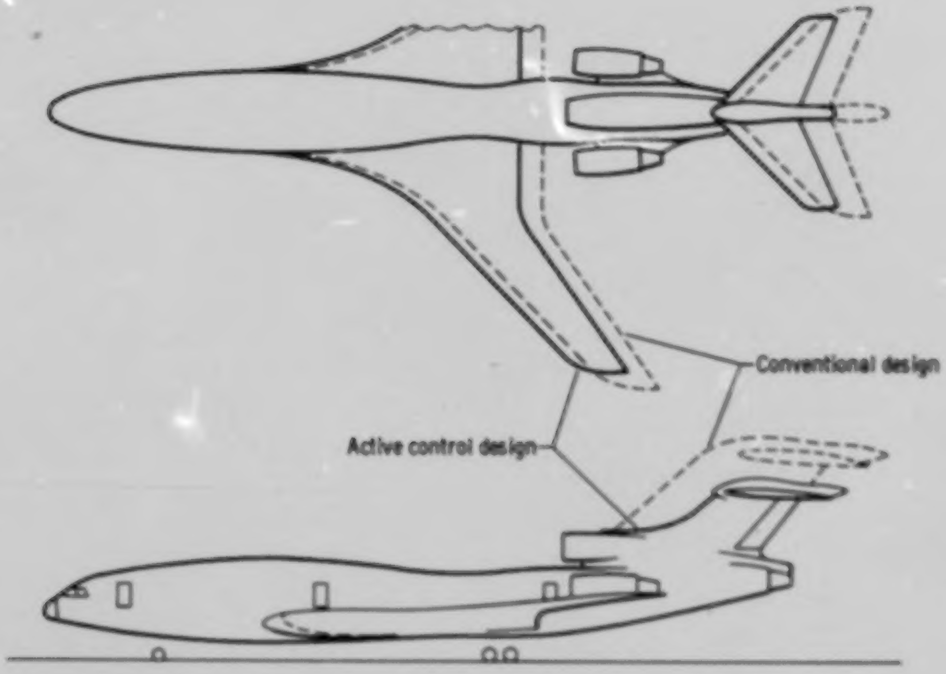
Conventional design
Active control design

Figure 23.- Comparison of conventional and active control design configurations.

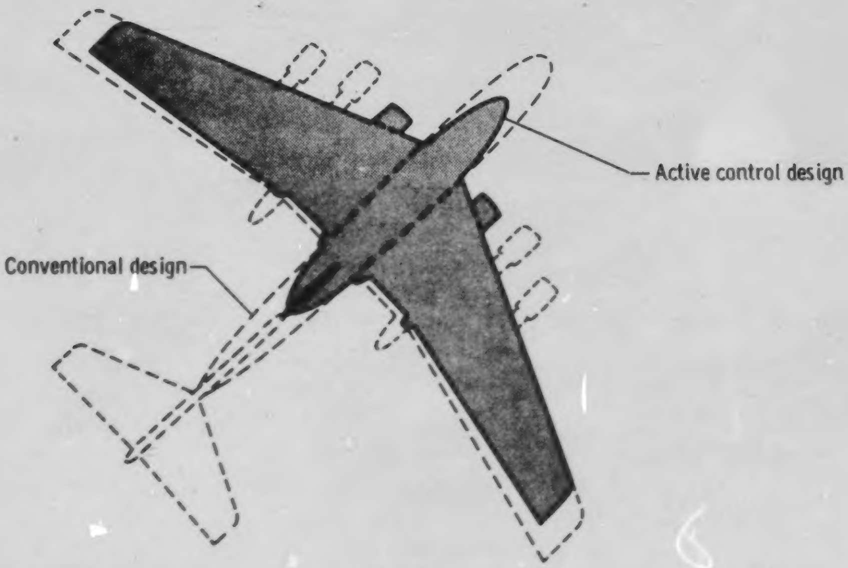
Active control design
Conventional design

Figure 24.- Comparison of a conventional and active control design of an advanced tanker aircraft.

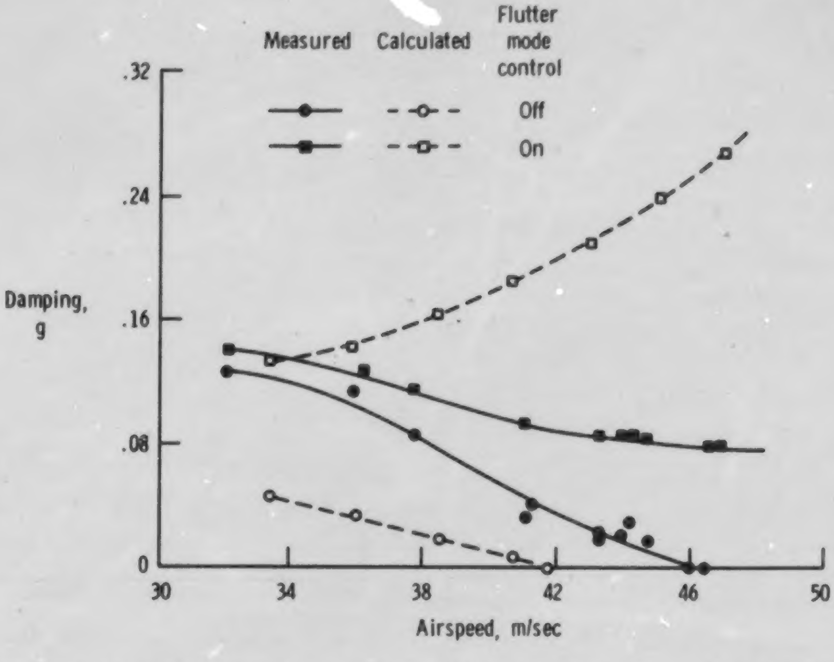

Figure 25.- Measured and calculated damping for a B-52 model.

OPPORTUNITIES FOR AERODYNAMIC-DRAG REDUCTION

By Robert E. Bower
NASA Langley Research Center

SUMMARY

Cruise drag is more important than any other single parameter in its effect on aircraft fuel consumption. The importance of fuel conservation in future aircraft has prompted NASA to initiate an extensive research program in aerodynamic-drag reduction. The basic areas of friction drag, induced drag, and pressure drag are receiving new attention. Airfoil research has received a revitalization with new concepts, theories, and facilities. Techniques to control the boundary layer are being investigated, and novel concepts are under development to reduce induced drag. Preliminary results from this research are encouraging and suggest a possible 50-percent reduction from current drag values. Attainment of this reduction will require extensive and imaginative work by researchers. The work is especially suited to the university laboratory, and an excellent opportunity exists for new thinking by joint NASA/university teams.

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INTRODUCTION

Aerodynamic efficiency, resulting in increased range and/or increased payload, has always been the goal of the aerodynamicist. Over the past several decades significant increases in cruise efficiency M(L/D) have resulted from research in airfoil shapes, swept wings, area ruling, and surface-roughness control. Advances in structures and materials have permitted use of thinner wings with higher aspect ratio without penalties in structural weight. Today's efficient subsonic jet transport is a result of that extensive effort.

The question might be asked, particularly by the college student, "Is aerodynamics a mature science? Are there no more opportunities for research with high payoff?" The answer should be an emphatic "No!" With today's rapidly accelerating fuel costs, for example, achievement of aerodynamic efficiency has never been more relevant. Nearly 70 percent of the fuel burned on a transcontinental trip is consumed during cruise. Cruise drag has more effect on fuel efficiency than any other single parameter. For example, a 1-percent increase in L/D results in a 1.35-percent decrease in fuel burned. Resizing the airplane to achieve this increase in L/D decreases fuel consumption even more (ref. 1).

The old areas of pressure drag, induced drag, and friction drag are being revisited by NASA. Figure 1 shows the contribution of these drag elements to the total cruise drag of a modern subsonic jet transport. Also shown are the opportunities for drag reduction and the means by which these gains might be realized. Success in a number of these research areas could result in a 50-percent reduction in cruise drag, a significant payoff. The purpose of this paper is to describe current work in drag reduction at the NASA Langley Research Center. Although a number of the concepts are applicable to higher speed regimes, the emphasis will be on subsonic-drag reduction.

SYMBOLS

AR	wing aspect ratio
c	chord of airfoil
c_ℓ	section lift coefficient
c_d	section drag coefficient
$C_{D,i}$	induced-drag coefficient
C_f	local skin-friction coefficient
C_L	wing lift coefficient
C_p	pressure coefficient
f_{peak}	peak power frequency in turbulent spectra
f_{vib}	membrane fundamental vibration frequency

L/D	aircraft lift-to-drag ratio
M	Mach number
R_N	Reynolds number
s	slot height
t	airfoil thickness
V	velocity
x	distance along surface
y	distance normal to surface
τ	shear stress

Subscripts:

o	value for no slot flow
s	value at slot exit
j	value at jet exhaust
rigid	value for rigid wall
∞	free-stream value

PRESSURE-DRAG REDUCTION

As shown in figure 1, the pressure drag of an efficient transport is only about 8 percent of the total airplane drag in cruise. Pressure drag results from flow separation and compressibility effects. For the purposes of this paper, the total pressure drag of the airplane is divided into that due to airfoil shaping and that which includes the separation drag of various components such as nacelles, fuselage, tail surfaces, and protuberances. Protuberance drag has been greatly minimized by attention to details such as lights, windshield wipers, antennas, and skin gaps or steps. Separation control on the fuselage boattail and in regions of component interference is more difficult and requires careful configuration design. Continued emphasis on drag cleanup, particularly for general aviation aircraft, could reduce pressure drag to values well below 5 percent.

Modern airfoils have no significant pressure drag at their design cruise condition. Difficulties do occur, however, when supercritical velocities are reached on the airfoil surface and/or maneuvering requires high angles of attack. In these cases, the flow separates and high pressure drag results. Langley recently initiated an extensive airfoil research program addressing these two areas of concern. This program will now be discussed.

Supercritical Airfoils

The first airfoils developed in this country to delay pressure-drag rise at high speeds were the NACA 1-series airfoils (ref. 2). The low-speed, high-lift characteristics of these airfoils, however, were poor. The NACA 6-series airfoils (ref. 3) corrected these deficiencies somewhat; and these, or their derivatives, were used on most of the first-generation subsonic jet aircraft. The first airfoils designed specifically to delay drag rise by improving the supercritical flow on the upper surface were the "peaky" airfoils of Pearcey (ref. 4). These airfoils provided an increase of 0.02 to 0.03 in the drag-rise Mach number and found application on the second generation of wide-bodied jet aircraft.

Nearly 10 years ago, Whitcomb (ref. 5) proposed the supercritical airfoil to increase the drag-rise Mach number considerably. Reference 6 is a recent review of this work, much of which is still classified. The supercritical airfoil is characterized by a substantially reduced curvature in the middle region of the upper surface in order to reduce the local Mach number, decrease the strength of the resultant shock wave, and minimize boundary-layer separation. A large amount of camber is employed near the trailing edge to "recapture" the lift lost on the midchord area. The leading-edge radius is large and the trailing-edge closure angle is very small. A comparison of the drag-rise characteristics of an early 10-percent-thick supercritical airfoil design, a recent design, and an NACA 6-series airfoil is shown in figure 2. The drag-rise Mach number of the supercritical airfoils has been increased by more than

0.10 over that for the 6-series airfoil. The more recent supercritical design shows the elimination of drag creep (a slow increase in pressure drag due to the presence of supercritical flow on the upper surface). Supercritical airfoil sections have been flight validated on F-8 and F-111 aircraft.

The supercritical airfoil theory can also be applied to increase the section thickness ratio for an equivalent drag-rise Mach number. The first thick supercritical airfoil was developed by W. Palmer, of Rockwell International Corporation, and flight tested on the T-2C aircraft. This 17-percent-thick airfoil had the same drag-rise Mach number as the original 12-percent-thick NACA 6-series airfoil on the T-2C at the same lift coefficient. Increase in thickness can be used to decrease wing weight, increase fuel volume, or increase wing span, as discussed in the section of this paper entitled "Induced-Drag Reduction." The thicker airfoil can also be optimized for cruise at a higher lift coefficient.

A family of supercritical airfoils will be studied under the airfoil research program at Langley, with the range of interest shown in figure 3. To date, 4-percent, 10-percent, and 17-percent-thick airfoils have been designed and tested. A 14-percent-thick airfoil has just recently been designed. Compatible high-lift systems for these airfoils will also be studied.

Subcritical Airfoils

Except for the Wortmann airfoil, which has found application to soaring gliders, there have been no new subcritical sections since the old NACA series. The needs of general aviation for improved performance, particularly during take-off and climbout, resulted in the initiation of a new NASA series of subcritical airfoils. These airfoils employ some of the favorable characteristics of the thick supercritical sections.

The first new airfoil to be designed, the General Aviation Whitcomb-1 (GAW-1), is a 17-percent-thick section designed to meet the critical engine-out climb requirements of light, twin-engine aircraft. These requirements include a decrease in pressure drag at a lift coefficient of 1.0 with little or no penalty at cruise. An improvement in the maximum lift coefficient at low speed was also needed without high-lift devices. Figure 4, taken from reference 7, shows the performance of the NASA GAW-1 airfoil compared with that of a conventional NACA 65-series airfoil used today on general aviation aircraft. The flat variation in c_d for the NASA GAW-1 airfoil almost up to the design climb condition of $c_\ell = 1.0$ is evident. An 80-percent reduction in pressure drag was obtained at $c_\ell = 1.0$, with only a slight penalty in cruise drag ($c_\ell = 0.4$). This resulted in an improvement of 40 percent in c_ℓ/c_d at climb. Also, $c_{\ell,max}$ was increased about 30 percent and the airfoil possessed a more gradual stall. The NASA GAW-1 airfoil is currently being flight tested to verify these wind-tunnel results and to evaluate handling qualities.

Additional subcritical airfoils are being studied, with the range of interest shown in figure 5. Two airfoils intended to provide aerodynamic performance similar to that of the NASA GAW-1, but with thickness ratios of 0.21 and 0.13, have already been designed.

Airfoil Analysis Techniques and Experimental Facilities

It is not the intent of the Langley airfoil research program to generate a handbook of data. Instead, adequate design and analysis techniques, supplemented as necessary with wind-tunnel and flight-test results, are sought.

Considerable progress has been made during the past 3 years in providing theoretical methods for the design of both subcritical and supercritical airfoils. Theoretical techniques are well in hand for subcritical airfoils near their design point. The computer program of reference 8 was used to design the NASA GAW-1 airfoil. The final shape was defined after 17 iterations on the computer. Figure 6 shows the excellent agreement between theory and experiment for the NASA GAW-1 airfoil at the design climbout condition ($c_\ell = 1.0$). In cases of extensive separation, serious voids exist in the analytical techniques. Moreover, data from which mathematical models of the separated flow field could be developed have, until very recently, been nonexistent. The U.S. Army and NASA are currently sponsoring a program at Wichita State University to measure the quasi-steady flow characteristics about airfoils with substantial boundary-layer separation.

In the case of supercritical airfoils, a number of new techniques have been formulated to solve the inviscid, nonlinear, transonic-flow equation, and, in some instances, inviscid analyses have been coupled with boundary-layer solutions. One such routine has been developed by Bavitz (ref. 9) using an inviscid airfoil analysis program developed at New York University by Garabedian and Korn (ref. 10) and a turbulent boundary-layer analysis method of Bradshaw (ref. 11). Bavitz' method underpredicts the pressure jump through the shock. Recently, Antony Jameson, of New York University, has formulated the problem with the more accurate finite-difference calculation of Murman (ref. 12) for the shock pressure jump. Figure 7 shows the comparison of pressures obtained by this method and experimental pressures on an 11-percent-thick supercritical airfoil at $M = 0.78$ and $c_\ell = 0.576$. The agreement is excellent except for shock location. A Mach number uncertainty of 0.004 due to tunnel-wall effects is not uncommon. A calculation at $M = 0.776$ predicts a shock location in agreement with the experiment. These techniques are now believed to be adequate for design calculations involving weak shocks and thin boundary layers. They were used to design the most recent 14-percent-thick supercritical wing. Much more research is required, however, in the cases of off-design performance prediction.

Langley has committed itself to a modernization of its airfoil test facilities. The Langley low-turbulence pressure tunnel (fig. 8), constructed in 1940, was used in early NACA series airfoil studies. It has recently been recertified for full pressure operation, so that it will continue to be the workhorse for subsonic airfoil development. The initial supercritical airfoil work of Whitcomb was carried out in the Langley 8-foot transonic pressure tunnel. This is an inefficient use of such a large facility; therefore, several other facilities have been constructed. The 6- by 19-inch transonic tunnel has been in operation since 1971. The 6- by 28-inch transonic tunnel has just become operational. A new high Reynolds number 8- by 24-inch cryogenic tunnel will become operational next year. These facilities are illustrated in figure 8, and their operating ranges of Mach number and Reynolds number are shown in figure 9. All these facilities are, or will be, equipped with modern data acquisition systems and precision instrumentation. They will allow tests up to full-scale Reynolds numbers for most aircraft types. Two areas still of concern, however, are tunnel wall effects at transonic speeds and sidewall boundary-layer interactions. Research will be conducted to develop tunnel techniques for the minimization of these effects.

INDUCED-DRAG REDUCTION

For most transport aircraft, the induced drag, or drag due to lift, is approximately 42 percent of the total drag at the cruise condition and may be more during climb. Induced drag is a function of wing planform. A wing of finite span introduces trailing vortices which produce a downwash at the wing. This downwash results in a rotation of the wing-force vector backward and thus creates an induced component of drag. It is important to recognize that induced drag is associated with the energy left behind in the fluid as a result of the trailing vortices. Concepts to reduce induced drag must be concerned with diffusing these tip vortices.

Vortex Diffusers - Winglets

The use of end plates to reduce induced drag was involved in a patent obtained by Lanchester in 1897, although the first experiments utilizing end plates did not take place until about 1924. Since that time, end plates have been suggested on a relatively continuous basis as a means for reducing induced drag. Applications to date, however, have shown that for cruise lift coefficients, the added skin-friction drag of the end plates more than offsets any reduction in induced drag.

Just recently the concept of a specially tailored end plate has been proposed by Whitcomb. These winglike devices, or "winglets," at the tip of the main wing (fig. 10) are designed with the same attention to flow field detail as in the design of a main wing. For example, supercritical sections with appreciable camber are used. To minimize skin friction, the chords of the winglets are less than the wing chord, and the area is about 2 percent of the area of the main wing. The top winglet is attached near the trailing edge, and the lower winglet is placed forward in order to minimize interference. The winglets are canted out from the main wing about 17.5°. The aspect ratio and sweep of the upper winglet are approximately the same as for the main wing. The lower winglet is "clipped off" for ground clearance. A recent addition has been a small vortex generator just inboard of the upper winglet to break up a small separation bubble. At this writing, the winglets are still under extensive wind-tunnel development. Preliminary results indicate induced-drag reductions of more than 15 percent.

The mechanism by which the winglets reduce the induced drag is not completely known at this time. One explanation is that the winglets create several trailing vortices which are weaker in combined strength than the usual single wing-tip vortex. A companion explanation is shown in figure 10. The local flow below the wing tends to flow outward, while the flow above the wing is inclined inward. Placing the winglets in this local flow field results in the development of side-force vectors which are inclined forward and thus produce a thrust component. This thrust component exceeds the profile drag of the winglets. The downwash effect on the main wing and therefore its drag component due to lift are also decreased.

The winglet concept is approaching the wing-tip configuration of soaring birds. It may be that Whitcomb is advancing a new nonplanar wing theory, since the winglets give greater performance than increased tip area. Since they offer retrofit possibilities, installation problems including flutter characteristics are under study. To date, only a slight reduction (about 1 to 2 percent) in the flutter speed has been noted (ref. 31).

Vortex Diffusers - Tip-Mounted Engines

Another method of influencing the wing-tip vorticity and the associated drag due to lift is the canceling effect of the high-energy wake of a tip-mounted, fan-jet engine. To explore more fully this possible phenomenon, an investigation was conducted in the Langley 8-foot transonic pressure tunnel (ref. 13). Figure 11 describes results for the basic unswept semispan model tested both with and without a simulated powered fan-jet bypass-ratio-8 engine at the wing tip. Test conditions were a Mach number of 0.7, a Reynolds number of 3.82×10^6, and a fan-jet pressure ratio of 1.5. The test data indicate that the powered fan jet reduced the induced drag by approximately 30 percent over that for the basic wing-tip model. This is a value below the theoretical minimum of $1/\pi AR$. At jet pressure ratios simulating cruise conditions, the drag reduction would be less. This reduction in induced drag is the result of a reduction in tip vorticity caused by introduction of the nonrotating engine wake into the flow at the panel tip. It might be expected that an even greater reduction in tip vorticity could be obtained by prerotating the engine-fan exhaust in a direction opposite to that of the vortex. The concept of engines mounted at the wing tip is continuing to receive attention. It has the added benefit of possibly reducing the wake-vortex hazard for following aircraft.

Over-the-Wing Blowing

Another way of utilizing the discarded energy in a jet-engine exhaust is to place the engine on top of the wing. This concept has already received attention for increasing the take-off and landing lift coefficients for STOL aircraft and for minimizing propulsion noise. In order to achieve quiet propulsive lift, the engine exhaust scrubs the wing surface and is turned around a flap (Coanda effect). This scrubbing action at cruise speeds produces an unacceptable friction drag.

An investigation of over-the-wing engine configurations that do not scrub the wing is currently under way. In this case, the jet exhaust induces an upwash on the wing. This upwash rotates the wing-force vector forward to create a negative induced-drag increment. The concept has been studied both analytically (ref. 14) and experimentally (refs. 15 and 16). Some results from these preliminary studies are shown in figure 12. The effects of increased jet velocities on induced drag are quite pronounced. Agreement between theory and experiment is believed to be excellent, particularly in view of the simplicity of the theoretical approach in reference 14. Data in this case were available only for the jet-off case and a jet velocity ratio corresponding to take-off conditions. The theory is used to predict performance at more representative jet velocity ratios at cruise and climb for a turbofan engine with a bypass ratio of 4. As shown, a decrease in induced drag of up to 12 percent in cruise and 20 percent in climb is possible. Much more experimental research work is required on this concept.

Increased Aspect Ratio

Since induced drag is inversely proportional to wing aspect ratio, the most direct way of reducing this drag due to lift is to increase the wing span. For an airfoil section of given thickness, however, this introduces increased wing-root bending moments and higher wing weight. The thick supercritical airfoil section can be used to minimize any weight increase as well as to maintain a relatively high drag-rise Mach number. The supercritical wing would be designed to have a greater aspect ratio and less sweepback and would result in an improved aerodynamic efficiency instead of an increase in cruise speed (fig. 13). An effort is currently under way to design a 14-percent-thick supercritical wing with an aspect ratio of 11. It is estimated that this wing will reduce induced drag by 30 percent and increase L/D by approximately 15 percent. Winglets can also be added to this wing for a total reduction in induced drag of 40 percent.

An advanced configuration type that adapts itself to high aspect ratio and low induced drag is the so-called span loader. In this concept the payload of the aircraft is located in the wing. Wing-root bending moments are minimal because the payload weight counteracts the wing lift force. Vehicles utilizing this concept will be very large and are potential cargo carriers.

Pushed to an extreme, the vehicle becomes a flying wing with very high aspect ratio and payload-to-gross-weight ratios more than twice present values. Such vehicles will require the development of very thick ($t/c \approx 0.25$) airfoils.

FRICTION-DRAG REDUCTION

Skin friction accounts for approximately one-half of the drag of current subsonic transport aircraft. It offers the greatest potential for drag reduction, but at the same time this reduction is the most difficult to achieve. Langley is currently revisiting concepts for laminar flow control and is looking at ways, both passive and active, to control and reduce turbulent skin friction.

Laminar Flow Control

Maintenance of a laminar boundary layer on a surface can reduce skin friction by as much as 90 percent. Although several techniques have been proposed to delay boundary-layer transition, for example, skin-temperature control, suction control, and blowing, only the technique of suction through the airplane skin has yet proven to be technically feasible. Maintenance of laminar flow over large portions of a surface has been verified in the wind tunnel as well as in flight tests by the U.S. Air Force on the X-21 back in 1964 (fig. 14). The principal technical difficulties in this concept are the high manufacturing costs of smooth slotted or porous surfaces, excessive suction-system weight, and practical methods for surface maintenance. Recent technology advances, however, offer considerable promise, for example, woven graphite-epoxy porous surfaces, laser or electron-beam drilling techniques, and light-weight composite ducting. In view of these developments, industry is being asked to define the characteristics of a subsonic long-range transport aircraft with laminar-flow control applied to the wing and empennage. Emphasis will be on systems design - particularly practical structural concepts. Success of this systems study could lead to flight demonstration.

Turbulence Control With Compliant Surfaces

On areas of the aircraft where it is impractical to maintain laminar flow, the fuselage, for example, it may be possible to reduce turbulent skin friction by means of compliant surfaces. These are flexible surfaces that are made to respond uniquely to the fluid motions in the boundary layer. Kramer (refs. 17 and 18) is credited with the original idea based on his observations of dolphins' skin. His early experiments on a cylinder with a compliant coating towed behind an outboard motor boat showed a drag reduction of approximately 50 percent. Kramer attributed this reduction to delayed transition, but it has since been theorized that the drag reduction was due either to an alteration of the shape of the cylinder or, more probably, a favorable interaction of the compliant coating with a turbulent boundary layer. Theoretical attempts to analyze this latter possibility are sparse and inconclusive (refs. 19 to 21).

There are more than 80 published compliant-wall data points which indicate a drag reduction, yet much ambiguity exists which limits the understanding and potential of this drag-reducing concept. Much of the confusion is doubtless caused by experimental technique. Parameters such as material type, backing materials, mountings, length, thickness, skin tension, boundary-layer thickness, roughness, dynamic pressure, and the presence of panel flutter must by systematically varied. This was the approach of a Langley study started approximately $2\frac{1}{2}$ years ago. Initial results from this study (ref. 22) demonstrated the need for selecting compliant wall materials which respond at relatively high frequencies with amplitude displacements less than the sublayer thickness. Figure 15, taken from reference 22, correlates existing data and suggests that maximum skin-friction reduction occurs when the fundamental membrane frequency f_{vib} is about half the peak power frequency in the boundary layer f_{peak}. An optimum vibration amplitude should also exist. Too large an amplitude (greater than the laminar sublayer) can produce an unwanted roughness effect. Too low a value retards the drag-reducing action of the membrane.

Bushnell et. al. at Langley have proposed a possible mechanism for compliant-wall drag reduction (fig. 16). Wall-pressure fluctuations in the turbulent boundary layer which act upon the compliant surface material cause it to respond at its characteristic frequency at an amplitude depending upon the dynamic pressure of the flow. This compliant-wall movement generates acoustical disturbances which feed back into the turbulent boundary layer. It is hypothesized that if these wall-generated disturbances are at some optimum frequency which is higher than the frequency of the energy-containing large-scale eddies in the outer portion of the boundary layer, a shattering, or breakdown, of the large-scale eddy structure may occur. Thus, the energy-cascading process wherein turbulent energy is transferred from the energy-containing large eddies to the smaller scale high-frequency dissipating eddies may be disrupted. To maintain equilibrium, a modified, lower turbulent-energy level develops in the boundary layer with a reduced wall shear. In support of this hypothesis, experimental evidence with jet flows exists (ref. 23) which indicates that low-frequency acoustic disturbances enhance the jet spreading (drag increase). Additional supporting evidence which illustrates the significant influence of acoustical disturbances on turbulence intensity and structure is given in references 24 to 26.

Preliminary compliant-wall test results recently obtained in the Langley low-turbulence pressure tunnel are shown in figure 17. Hot-wire, mean, and fluctuating (Reynolds stress) data were obtained in a turbulent boundary-layer flow over a rigid surface and various compliant surfaces. All the compliant surfaces tested consisted of 6.35-mm-thick (0.25-in.) compressed polyurethane foam with various surface coverings. The most effective combination was a 0.0254-mm-thick (0.001-in.) Mylar membrane stretched under tension and bonded to the foam substrate. Velocity profiles show a measurable reduction in boundary-layer thickness for the compliant wall. Shear stress measurements show a 20-percent reduction in skin-friction drag. Test conditions were varied over a velocity range of 31 to 91 m/sec (100 to 300 ft/sec) at Reynolds numbers of 6×10^6 to 110×10^6. Drag reduction varied from 10 to 20 percent over this test range. These results for "unoptimized" surfaces are encouraging. However, much research toward understanding better the mechanism of drag reduction and developing practical aircraft materials remains to be done.

Turbulence Control Through Slot Injection

Slot film cooling for hypersonic aircraft has been under study for some time (refs. 27 and 28). In this work, a dramatic reduction in turbulent skin friction behind the slot which persisted for several slot heights downstream was observed. A reduction of 15 to 20 percent in skin friction was also observed with slot injection at supersonic speeds (refs. 29 and 30). To date, however, there have been no direct measurements of skin friction in subsonic flow with slot injection. A high priority has been placed on obtaining these measurements both at Langley and on a university grant.

An illustration of the slot-injection concept is illustrated in figure 18. This low-momentum slot flow, injected tangentially to the surface at a velocity about 0.3 that of free stream, alters the velocity distribution in the boundary layer and reduces the skin friction. Predicted state-of-the-art values of skin friction are shown as well as possibilities with advanced turbulence control. Critical parameters to the success of this concept are slot base drag and the ram drag and weight of the air collection system. On the basis of existing calculations, significant improvements in slot base drag will be required for the benefits to outweigh the disadvantages. At a slot velocity ratio of 0.3, for example, current uncertainties in slot base drag are 60 percent or more. Within the next year, results from experimental and systems studies should permit a frank assessment of the feasibility of the slot-injection concept for aircraft application.

Other Concepts

Roughness sources from manufacturing irregularities can account for about 5 percent of the skin-friction drag - perhaps much more on general aviation aircraft for which fabrication costs are most critical. A recent development of the NASA Johnson Space Center offers a significant improvement in smoothness at low cost. In this process, a special plastic substrate is spread over the wing surface. While the substrate is still in the fluid state, a stressed plastic film is applied over it. The substrate flows and "fills" all surface irregularities and the stressed plastic film is securely bonded to the wing surface. The result is a surface as smooth as the plastic film itself. Total thickness of the film and substrate may be varied from 0.25 to 0.51 mm (0.01 to 0.02 in.) to remove relatively large surface irregularities. Experience on spacecraft indicates that a damaged surface is easily repaired. A section of a T-33 wing (2.4-m (7-ft) chord) as produced and with the special plastic surface will be tested this year in the Langley low-turbulence pressure tunnel to quantify drag reductions.

Several other concepts for viscous-drag reduction are also receiving attention. Tests are planned on a wall treatment utilizing sound absorbing material for passive control of the amount of noise reflected back into the turbulent boundary layer. Carrying this to an active system involves the possibility of injecting high-frequency acoustic disturbances into the boundary layer to reduce wall shear.

CONCLUDING REMARKS

Because of rising fuel costs, it is clear that aerodynamic efficiency has never been more relevant. The opportunities for aerodynamic-drag reduction are large, but the challenges are equally large. In many areas preliminary research results are encouraging. Some concepts appear ready for application, for example, supercritical technology and winglets. Others, such as compliant surfaces and slot injection, will require a great deal more research. The nature of drag-reduction research invites participation by the universities. The work is basic and in many instances the experimental equipment required is not sophisticated. Faculty and graduate students are encouraged to join NASA in revisiting this exciting frontier.

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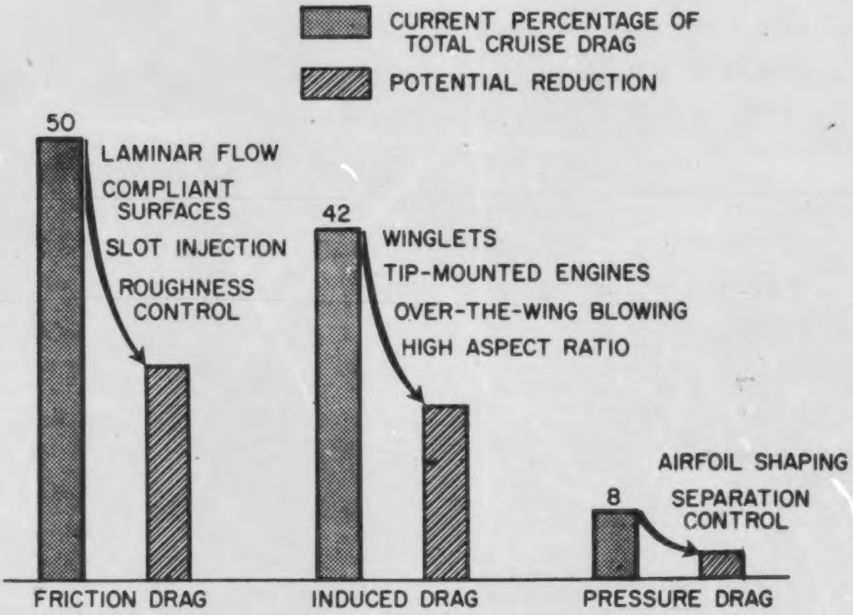


Figure 1.- Opportunities for subsonic-drag reduction.

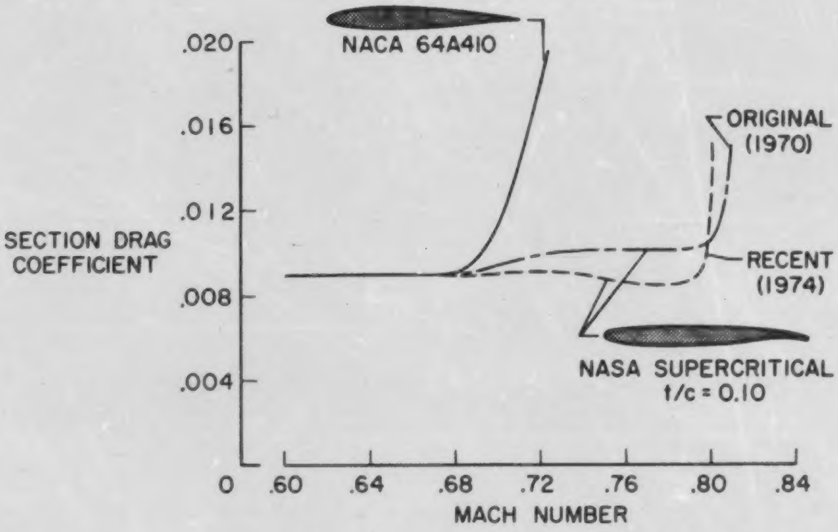


Figure 2.- Improvement in airfoil drag-rise characteristics. $c_l = 0.7$.

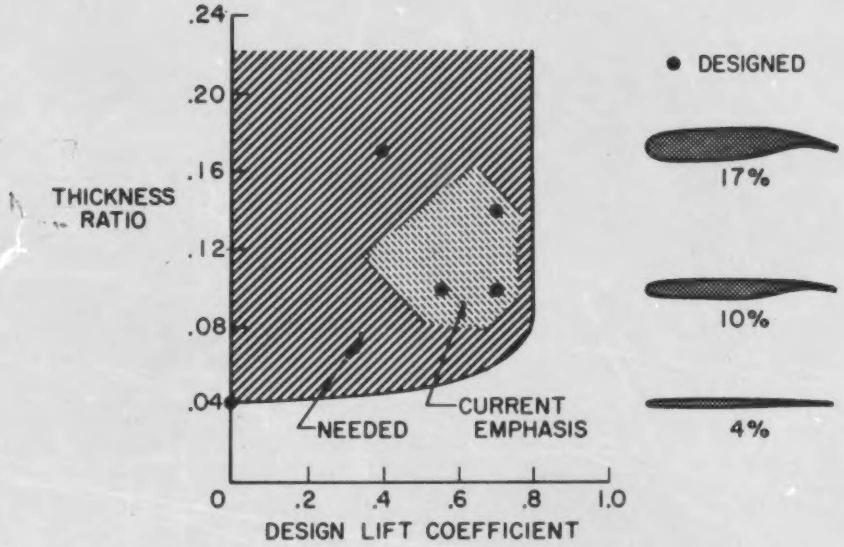


Figure 3.- Family of supercritical airfoils.

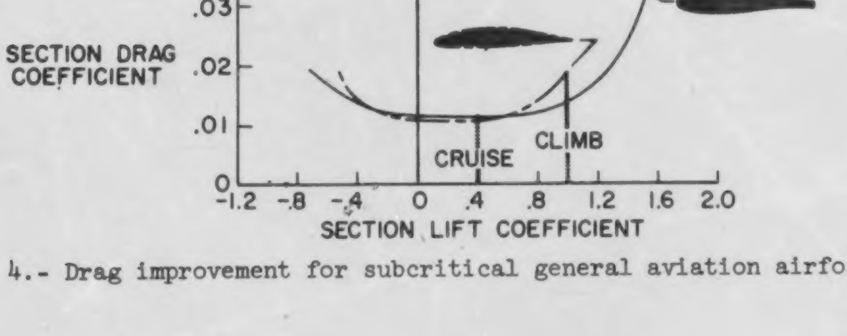


Figure 4.- Drag improvement for subcritical general aviation airfoils.

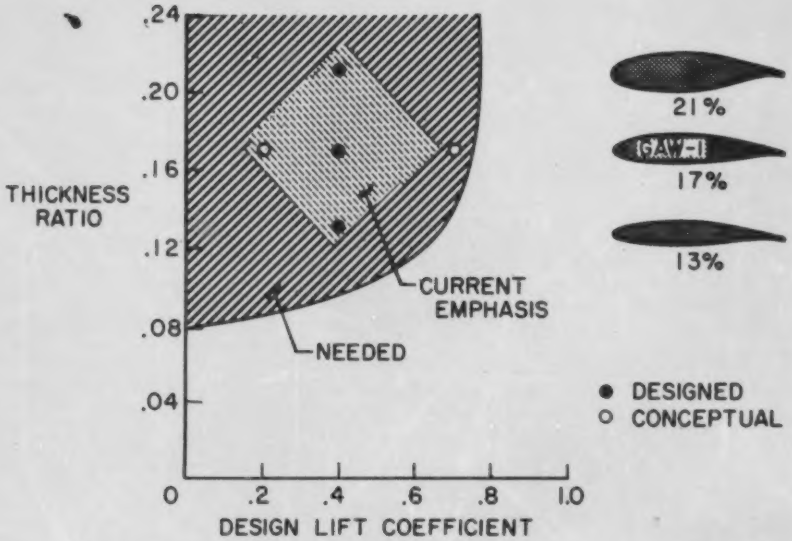


Figure 5.- Required family of subcritical airfoils.

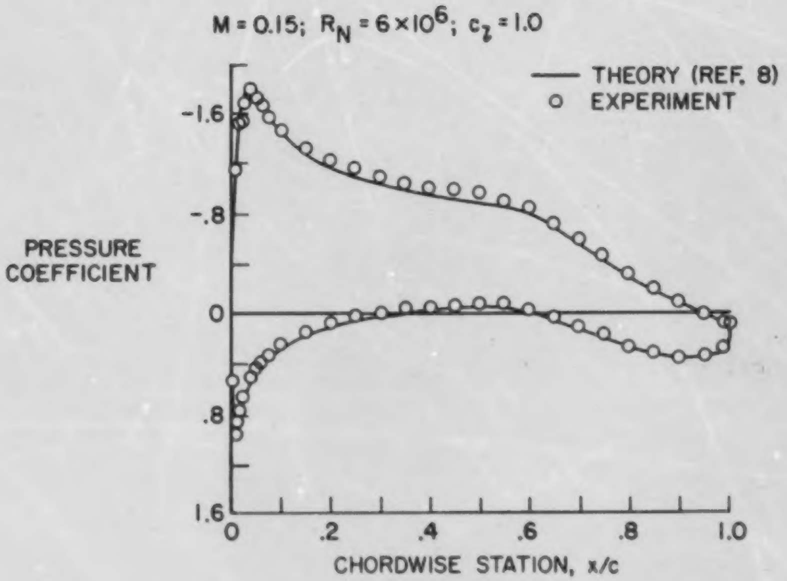


Figure 6.- Subcritical airfoil predictions (GAW-1).

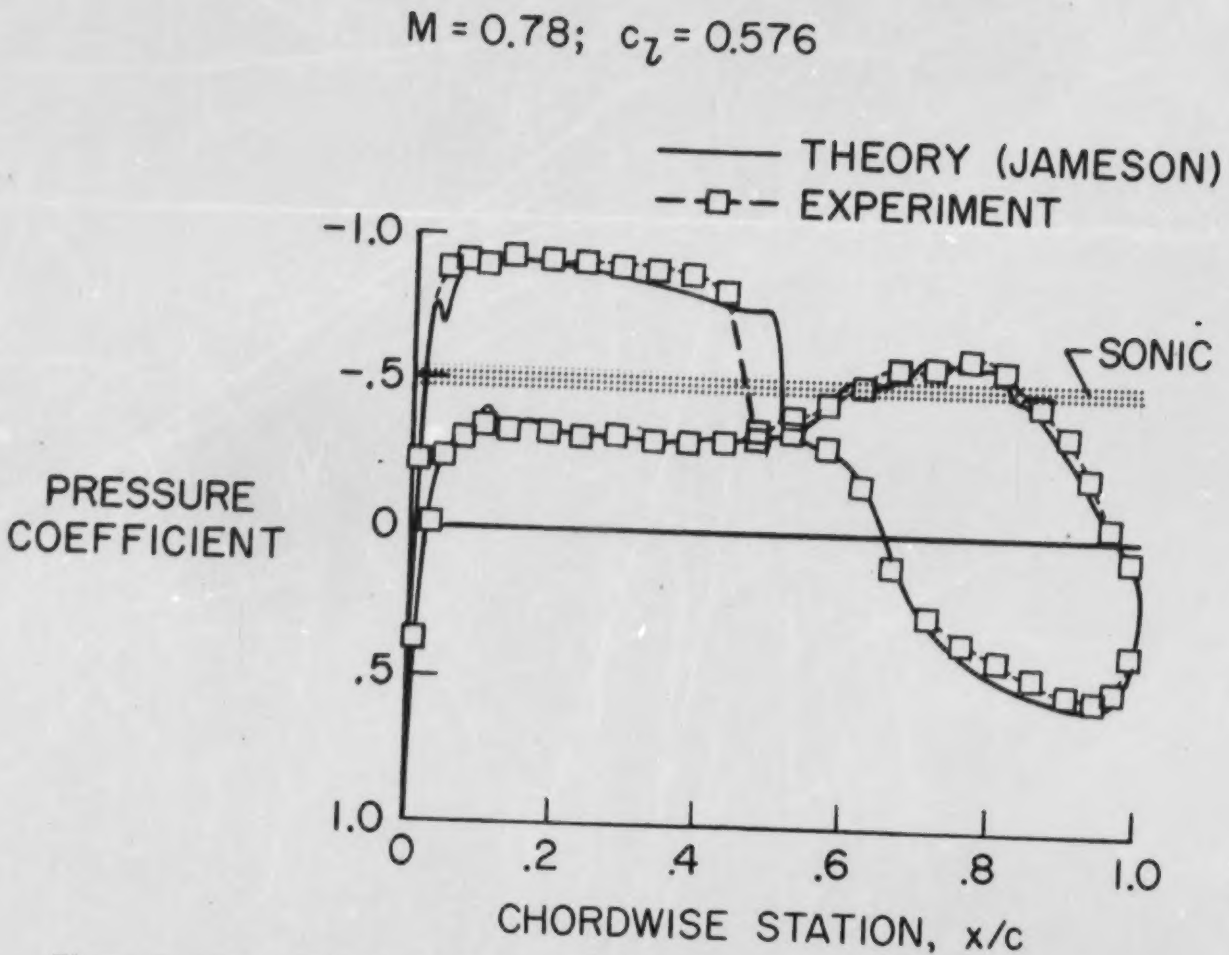
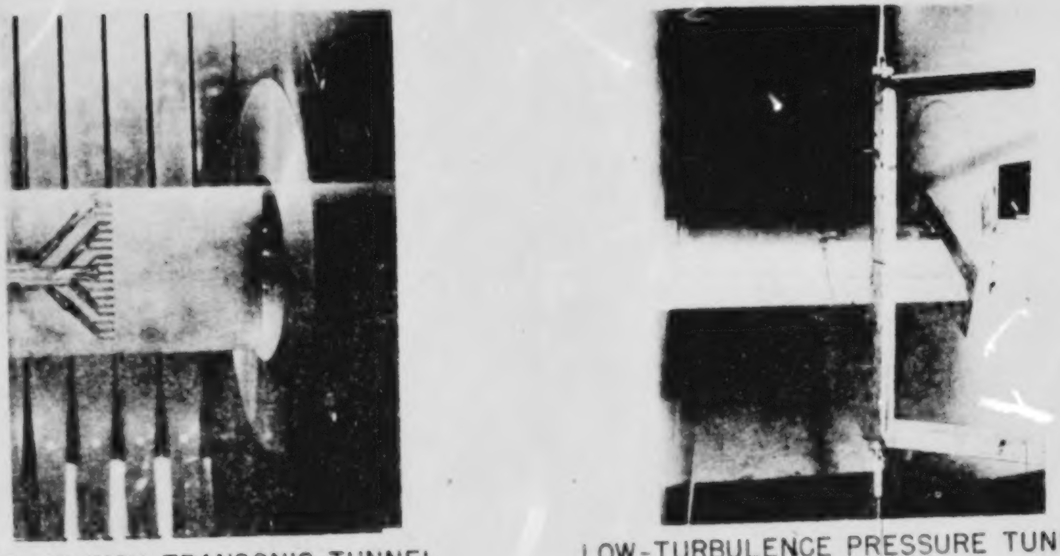
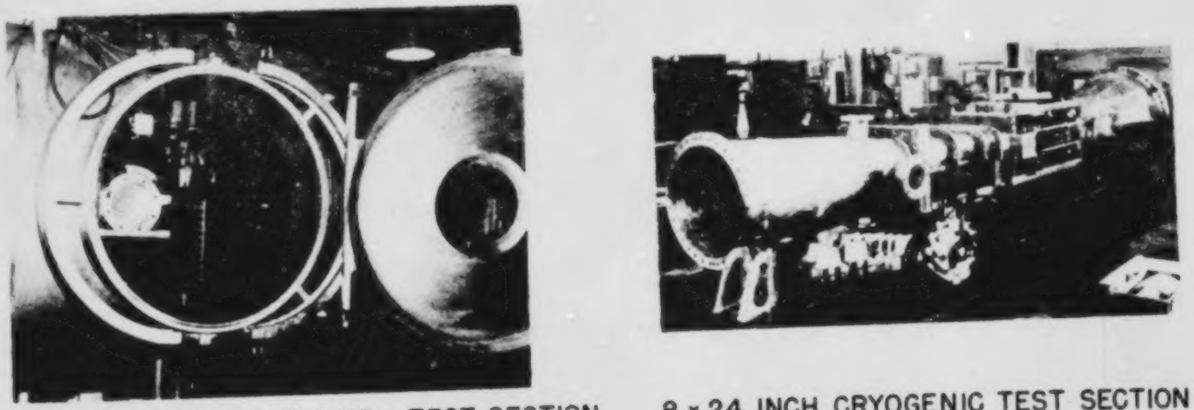


Figure 7.- Supercritical airfoil predictions (NASA supercritical, t/c = 0.11).



6 x 19 INCH TRANSONIC TUNNEL

LOW-TURBULENCE PRESSURE TUNNEL



6 x 28 INCH TRANSONIC TUNNEL TEST SECTION

8 x 24 INCH CRYOGENIC TEST SECTION

Figure 8.- Langley airfoil research facilities.

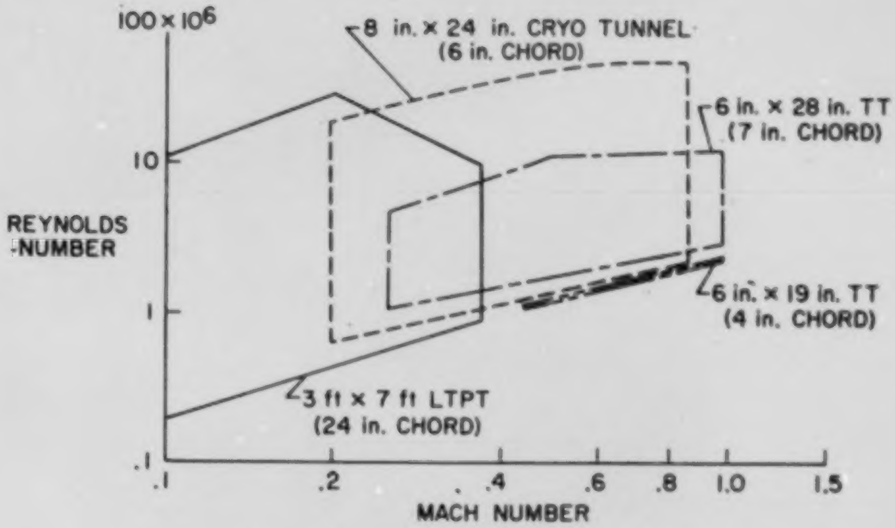
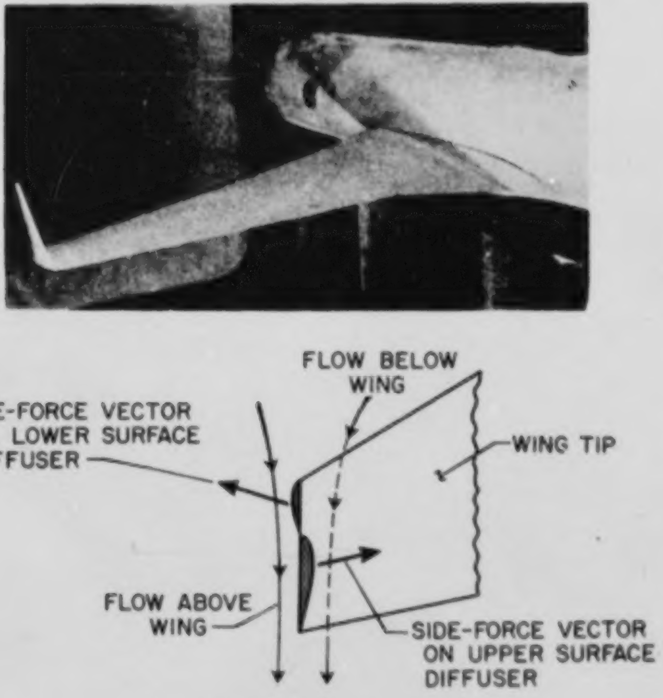


Figure 9.- Langley test capability for airfoil research.


FLOW BELOW WING
SIDE-FORCE VECTOR ON LOWER SURFACE DIFFUSER
WING TIP
FLOW ABOVE WING
SIDE-FORCE VECTOR ON UPPER SURFACE DIFFUSER

PROPOSED FLOW MECHANISM

Figure 10.- Concept of wing-tip vortex diffusers (winglets).

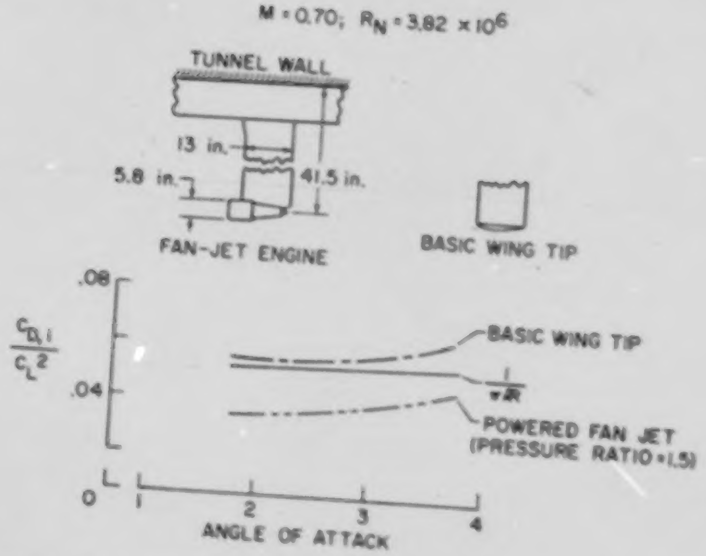


Figure 11.- Experimental results of a semispan model with a fan-jet engine mounted at the wing tip.

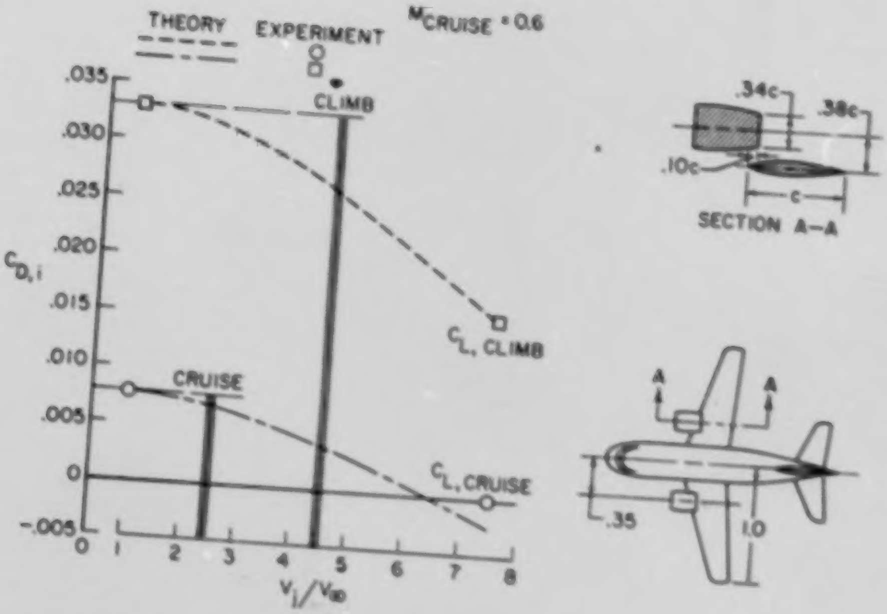


Figure 12.- Induced-drag reduction by over-the-wing blowing.

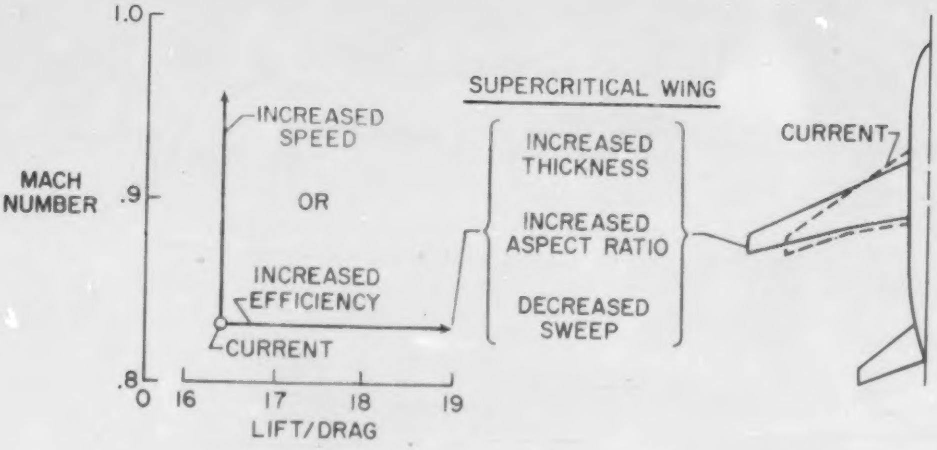

1.0
.9
.8
0
MACH NUMBER
INCREASED SPEED
OR
INCREASED EFFICIENCY
CURRENT
16
17
18
19
LIFT/DRAG
SUPERCRITICAL WING
INCREASED THICKNESS
INCREASED ASPECT RATIO
DECREASED SWEEP
CURRENT

Figure 13.- Use of thick supercritical airfoils to reduce induced drag.

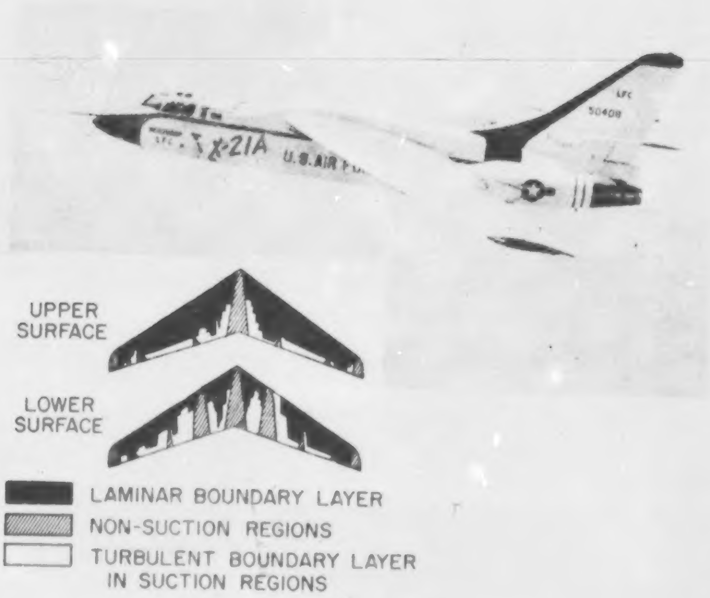

X-21A
U.S. AIR FO
LFC
50409
UPPER SURFACE
LOWER SURFACE
■ LAMINAR BOUNDARY LAYER
▨ NON-SUCTION REGIONS
□ TURBULENT BOUNDARY LAYER IN SUCTION REGIONS

Figure 14.- X-21 LFC aircraft.

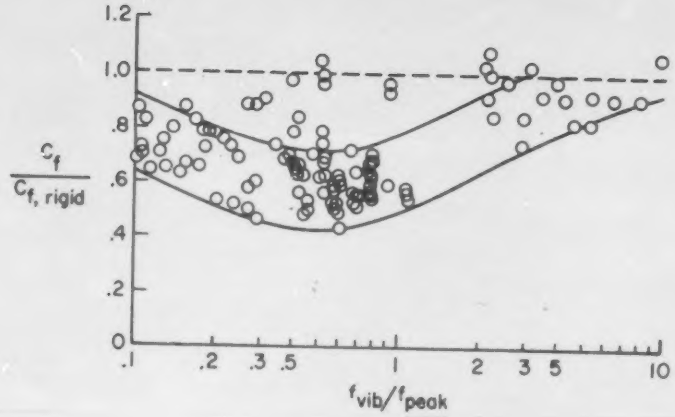


Figure 15.- Compilation of experimental data on compliant-wall drag reduction.

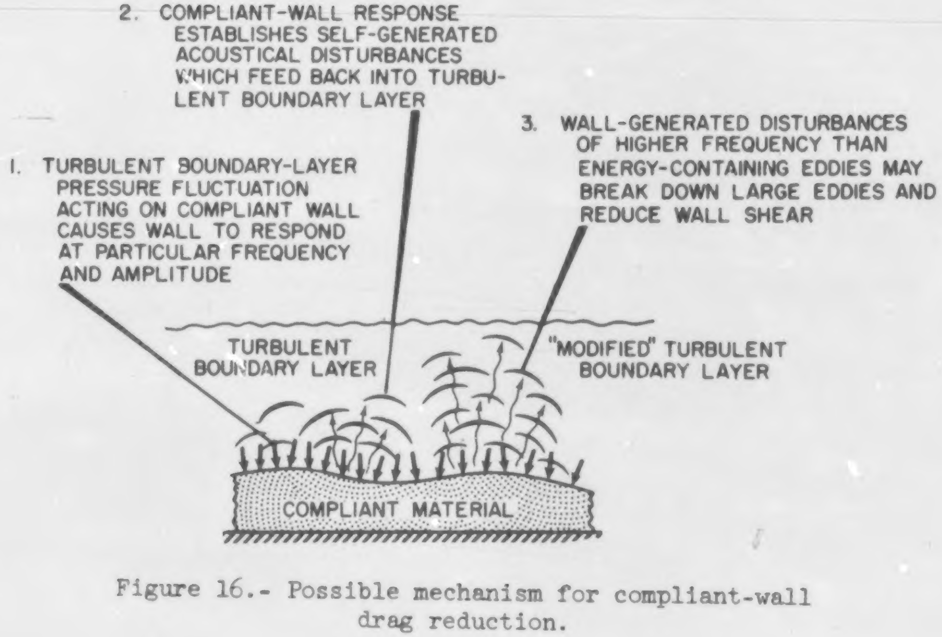

2. COMPLIANT-WALL RESPONSE ESTABLISHES SELF-GENERATED ACOUSTICAL DISTURBANCES WHICH FEED BACK INTO TURBULENT BOUNDARY LAYER
3. WALL-GENERATED DISTURBANCES OF HIGHER FREQUENCY THAN ENERGY-CONTAINING EDDIES MAY BREAK DOWN LARGE EDDIES AND REDUCE WALL SHEAR
1. TURBULENT BOUNDARY-LAYER PRESSURE FLUCTUATION ACTING ON COMPLIANT WALL CAUSES WALL TO RESPOND AT PARTICULAR FREQUENCY AND AMPLITUDE
TURBULENT BOUNDARY LAYER
"MODIFIED" TURBULENT BOUNDARY LAYER
COMPLIANT MATERIAL

Figure 16.- Possible mechanism for compliant-wall drag reduction.

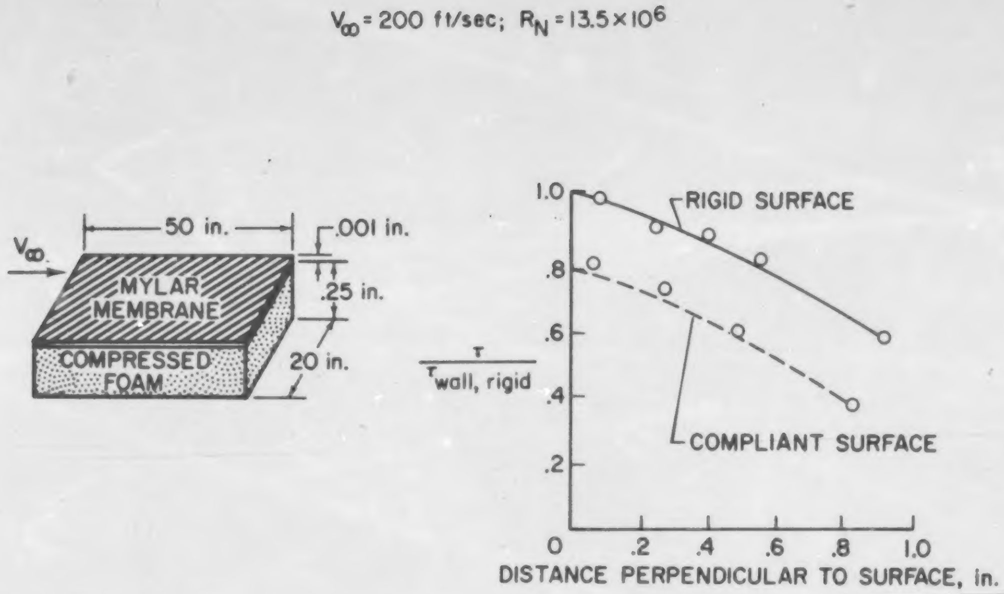


Figure 17.- Experimental results of compliant-wall drag reduction.

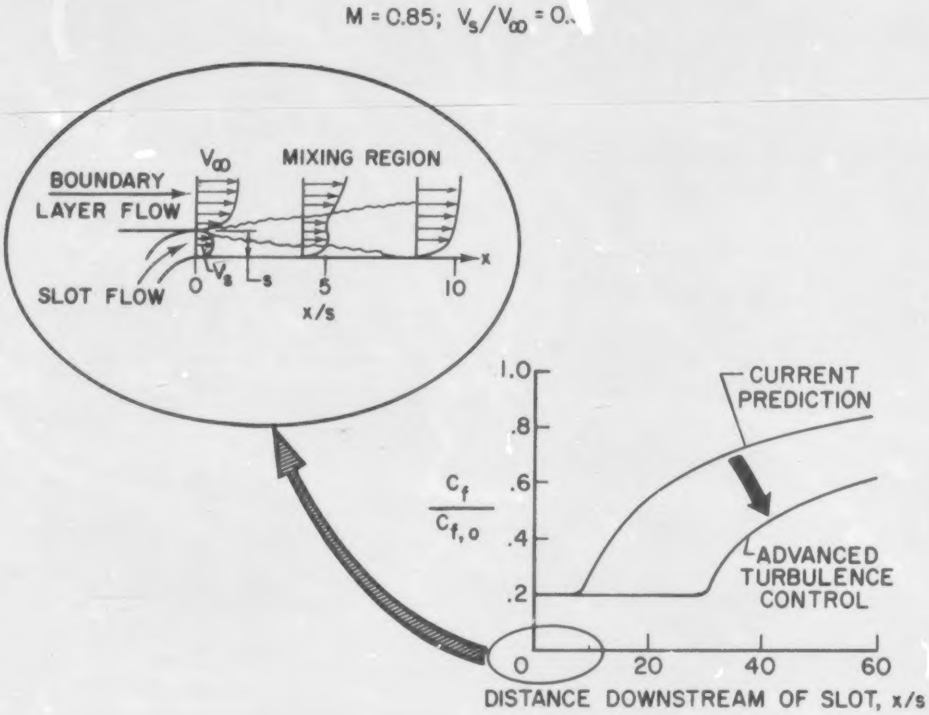


Figure 18.- Theoretical predictions of drag reduction through slot injection.

SESSION III

A FORUM ON THE ROLE OF THE UNIVERSITY IN AERONAUTICS

PANEL I
UNIVERSITY/GOVERNMENT/INDUSTRY RELATIONS

THE ME/DE DEGREE AT THE UNIVERSITY OF KANSAS

By Kenneth H. Lenzen
The University of Kansas

Coupling the normal educational system at any degree level with industry is difficult except under special conditions, and then quite often the coupling is not satisfactory to all the participants. At the University of Kansas we have devised a working agreement at the graduate level which has been satisfactory to the student, industry and university and which does require close coupling. It has the added attractiveness that the faculty and students must be working with the state-of-the-art in the projects.

In 1966 NASA, under the direction of James E. Webb, and the Engineering Administration at the University of Kansas, under the direction of William P. Smith, both came to the conclusion that a more practical industry-oriented design and development program at the doctoral level was needed in Engineering. In 1967 NASA funded five schools, which were Stanford, Cornell, Georgia Tech, Purdue, and the University of Kansas, to implement within their doctoral engineering programs a design-development type of program.

Th University of Kansas received approval of a Master of Engineering/Doctor of Engineering program under the auspices of the Graduate School in addition to the M.S. and Ph.D. department degrees. This was to be a practical engineering degree equivalent to the Ph.D. and M.S. degrees at the University of Kansas, but to be design and development oriented rather than research oriented. The other four schools on the approved list modified their existing Ph.D. degrees to conform with NASA's requirements. It is my understanding that these four schools do not emphasize the program at this time.

The University of Kansas not only pushed the degree at that time, but is still actively engaged in the Doctor of Engineering program. Although some of the faculty accepted this new program with reluctance in 1967 and 1968, most of the faculty are now enthusiastic about the Doctor of Engineering program.

The Doctor of Engineering program involves a technical education in the area of interest above that of the M.S. degree. In addition, there is a core of systems, design, business, and technology and society courses which all students must take. Twenty-four hours are required in the core area. The original courses as modified with time still exist. A recent review has indicated a need for change. The core will remain, but it is the hope that the student will have a selection of 30 hours in these areas from which to pick 24 hours. The areas will be changed such that system analyses and design will be integrated to a further extent. The business area will be expanded. Areas such as technology assessment and forecasting will be added.

A half year of internship is required at the M.E. level. Since at this level a student may not have had any industrial experience, especially in engineering, he can fulfill this requirement in two summer sessions. At the D.E. level a full, continuous year of internship is required. The program has been organized so that the School of Engineering will provide positions for the student if requested. The third major variation from the Ph.D. dissertation is to a design or development project. This project is to be a team effort which the D.E. aspirant supervises. He is to provide the supervision necessary for the conduct of the project. Reports from the graduate and undergraduate students on the project appear within the body of the project report or as appendices. The project report is filed exactly as our Ph.D. dissertations. The total requirements, as far as hours and examinations, are the same as the M.S. and Ph.D. requirements.

Industries have come to know these students. They are in demand by many of the governmental agencies and private industries that have had experiences with them. Further, the salaries are in general higher than those of the equivalent Ph.D. student. More demands are being made on us to satisfy these requirements.

The faculty has found that handling the D.E. project is much more exciting and much more can be accomplished than under the Ph.D. dissertation. Something is always happening. It isn't a formal report once a week on the solution of some differential equation.

We are realizing but little problems in providing internship and projects in the areas of the student's interest. Industry and governmental agencies have cooperated in general with enthusiasm. NASA-Langley has been especially helpful with this program and we are receiving an excellent reception from the other NASA research laboratories.

At present we have graduated approximately 20 Doctor of Engineering degrees. They are scattered throughout government, private industry, and some of the universities. The sheets which I have made list the graduates and where they are working. Another sheet indicates their projects. We at the University of Kansas are enthused with this degree and we feel that it is a degree that hard scientists and engineers would have followed if they had not felt it necessary to conform to the Ph.D. when they first started graduate work.

One obvious advantage of the D.E. degree, since it is a school degree rather than a department degree, is the interdisciplinary possibilities. We have had several interdisciplinary projects between Aero and Electrical, between Civil and Aero, between Electrical and Geography, and between medicine and Electrical. We are now setting up projects between Geology and Civil and other such areas. We have the freedom to move in any disciplinary area that is justified by the industry or the student's interest.

In the last two years we have received inquiries from four or five schools on this program. We are sure you will see some form of this program at many of our engineering schools in the future.

A PROPOSED UNIVERSITY/INDUSTRY/GOVERNMENT COOPERATIVE AERO EDUCATIONAL PROGRAM*

By Robert F. Brodsky
Iowa State University

INTRODUCTION

A program is proposed to provide mutual aid between the beleaguered Aero Engineering degree-granting departments in the United Stated and United States industry/government. It is proposed that any accrued cost differentials be supported by the latter groups, although all programs proposed will provide true mutual assistance. The program suggested is designed to provide assured industrial experience for Aero faculty members, combat engineering obsolescence for industry engineers, provide assured summer work for Aero undergraduates, encourage industry/government input in curriculum and course planning, and funnel significant laboratory devices into the university system.

The idea for this program of initiative proposals stemmed from an inspection trip of French Aero Engineering Schools (Reference 1) made by the author in the Fall of 1973. The principles embodied in the first three initiative programs are similar to the standard practice of the top French Aero Schools. It therefore appeared appropriate to seek support from the directly affected group of educators - the Aerospace Department Chairmen's Association (ADCA), which organization, described below, is continually seeking ways to improve and promote Aero education.

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* The author acknowledges the aid of the Engineering Research Institute of the College of Engineering, Iowa State University, in the preparation of this paper.

ADCA (Figure 1)

The Department Heads of the approximately 59 U.S. university departments which offer degrees in Aero Engineering are seeking considerably strengthened ties with and technical/financial/equipment support from the Aerospace industry. Starting in 1970, these departments formed ADCA in the hopes of providing a clearer voice to save an endangered species - the Aerospace Department - which flourished in the 50's and 60's but met and is still contending with severe enrollment set-backs as a result of industry declines. To this end, ADCA maintains up to date enrollment figures of Aero engineering students, has published (with the aid of the Aerospace Industries Associates) a widely accepted brochure, "So You Want to be an Aeronautical or Aerospace Engineer?", and has provided AIAA with an unambiguous position regarding the non-acceptance of the proposed five-year "Advanced Degree" accreditation program. The present ADCA Chairman is Professor Barnes W. McCormick of Pennsylvania State University and the Secretary/Treasurer/Chairman-elect is Professor R. F. Brodsky of Iowa State University.

SUMMARY

Three major factors have led to the Brodsky-formulated initiative measures: (1) the concern that industry/government, the major "users" of the university products, is not sufficiently concerned or aware of the educational problems in Aero; (2) the concern that, because Aero faculties no longer have dynamic turnovers or widespread opportunities for consulting and summer work (because of the enrollment decline), the faculty members are losing touch with the "real world" problems; and (3) the concern that, in most cases, only the top students in each graduating class have the opportunity to see first hand what industry is like; the great majority not having a chance for summer indoctrination. The measures proposed below are designed to combat these deficiencies while providing industry/government an opportunity to take positive steps about their "engineering obsolescence" and recruitment problems.

The proposed four point program involves the following (Figure 2):

1. Professor/Engineer Exchange - calls for the establishment of a clearing house to advertise and initiate exchanges on a 9-month or calendar year basis. Each Aero degree-granting department would be permitted at least one such exchange per year at all professorial rank levels. Exchanges would not necessarily be on a one-to-one basis. Each organization would continue paying its employee, with differentials being "made up" by industry/government.

2. Students-in-Industry - is suggested on the basis that a summer (between the Junior and Senior years) in industry/government is a necessary training experience for every Aero student in an accredited B.S. Aero curriculum. It is proposed that industry/government provide approximately 1500 such jobs through a clearing house which would match billets with student desires. The brunt of such matching could be accomplished by university engineering placement offices. Students would be paid on a similar scale to normal "co-op" students. Academic credit could be provided.

3. Curriculum Development - acknowledges that Aero Departments require much more guidance from industry/government on the relevance of their course of study and its content. The proposed program suggests that industry/government finance 2-to-3-day campus visits to 2-4 of a department's selected alumni for curriculum conferences. Such visits would be on a one per year or lower frequency basis. Such conferences would assure industry/government of a supply of properly trained neophyte engineers.

4. Surplus Equipment - suggests that Aero Departments be given "first crack" at obtaining surplus facility and instrumentation equipment which would normally be routinely junked or sold. Industry/government would maintain and disseminate (through a clearing house) listings and descriptions of material. Allocation would be impartial, based perhaps on "shopping lists" provided to the clearing house by the departments. Arrangements should include financial aid in packing/shipping of

substantial equipment as well as technical services, where required.

To assure the reasonable unanimity of Aero Educators, the membership of ADCA has been polled to achieve a "Vote of Confidence" for the initiatives. The complete text of the statement, modified by minor feedback comments, is presented in the next section. To date, ballot returns are preponderantly in favor of the initiatives. With this encouragement, the author will permit an article containing the complete text to appear in an early 1975 issue of "Astronautics and Aeronautics" in order to acquaint AIAA membership with the thoughts of their academic brethren. Following ADCA confirmation in December, the text will be submitted to the Education Committee of the AIAA via the Vice President for Education, Dan DeBra of Stanford University, with a request that the matter be placed on the agenda of the February 1975 meeting of the Education Committee for action. Since the author is a member of this committee, at least one positive vote is assured.

PETITION

The following is the text of the petition to be summitted to the Education Committee of the AIAA for consideration:

A Proposed University/Industry/Government Cooperative Educational Program

We, the Aerospace Department Chairmen's Association (ADCA), representing ≈59 Aero degree-granting university level academic departments, hereby petition the AIAA (perhaps through its corporate membership) to provide actual active support to the programs proposed herein by assuming leadership in their recommendations, initiation and operation or to responsibly advise us as to other courses of action to follow to achieve our goals. We recognize that we are asking for special privileges limited to that segment of engineering training variously called "Aeronautical, Aerospace, Aero/Astro, etc."; but, as will be outlined in the preamble below, we believe that the AIAA is the "special interest" group that best represents us.

Preamble

The basic premises of this suggested program for University/Industry/Government innovative interaction are four-fold:

1. The Aerospace Industry consistently hires the great majority of students receiving Aero degrees. The cut-back in aerospace industry activity has caused Aero Engineering Departments to become a beleaguered and endangered species. Student enrollment has sharply declined and only now is indicating a "leveling out" or slow recovery. Predictions of total engineering enrollment in the next decade also indicate at best a slow growth. The net result is the fact of constant or declining numbers of Aero teaching/research staffs, with most faculty tenured, and little possibility for the infusion of new ideas or people into the academic ranks unless heroic efforts are made. This is an especially alarming situation in a technology-spearheading industry such as ours.

2. That the American Aerospace Industry, being the major employer of the Aero E. graduates of our universities, not only should have a significant "say" about the course of instruction of Aero engineers, but also stands to realize positive gains in a closer alliance with Aero faculty and student bodies by encouraging and participating in the proposed program. This assistance should stem both from AIAA corporate members as well as the other industry/government employers of Aero graduates. It should be pointed out that "special treatment" in our case is well-justified, since other types of engineering graduates, which the AIAA also represents, can easily find employment outside the Aerospace sector.

3. That the proposed program be a two-way street. Both industry/government and the universities will benefit. Industry will gain by having a bigger say in the education of its future engineers, will have available an infusion of new ideas, will realize savings on their

recruitment program, and will have a positive means of combatting obsolescence of their veteran engineers. Universities will gain by improved curricula, improved training facilities, bringing their professors in contact with modern "happenings," and their students in contact with the reality of the working world.

4. That the AIAA is the only technical society that is directly concerned with Aero Engineering, even though its membership also consists of engineers who have been trained in other technical disciplines. This is evidenced both historically (early membership in the IAS and ARS consisted mostly of pioneering Aerospace Engineers) and factually (the AIAA is solely responsible for Aerospace curriculum accreditation). Thus, if the proposed pilot program is deemed worthwhile, other technical societies could develop similar programs for their constituents (e.g., ASME for Mechanical Engineers, IEEE for Electrical/Electronic Engineers, etc., if such special help is needed). Note that ADCA hopes that the AIAA will spearhead this program by seeking industry/government encouragement and cooperation by persuasive means, and by offering to act as a "midwife" rather than as a comptroller, once the program is established.

The Four Point Program

The ADCA initiatives propose mutual aid programs in the following four areas, which will be discussed in greater detail below, and which will clearly require more thought before they become reality:

1. Routine Professorial exchanges with industry/government
2. Routine paid summer employment in industry/government for all Aero students (except Co-ops) between their junior/senior year.
3. Routine industry/government school alumni aid in curriculum planning with such visits financed by industry/government
4. Routine organized notification/distribution of surplus facilities/equipments to Aero Departments.

Initiative 1 - Professor/Engineer Exchange

It is proposed that AIAA act as a "clearing house" to arrange university aerospace faculty exchanges, with industry engineer/scientists. Time of such exchanges for a professor would be either for an academic year (~Sept.-June) or a full calendar year (~Sept.-to-Sept.). For the industry/government employee, shorter times (e.g., a quarter or a semester) are possible so long as a replacement is available to "cover" the professor's time away from school. Each academic department in the U.S. granting a B.S. Aero degree would be permitted one* exchange every year, so long as there were willing applicants. Assistant, Associate, and Full Professors would be eligible. Positions should be arranged in industry/government in the areas of their interest. Each department having a professor on such leave would agree to take an industry/government engineer in return as a visiting professor. This person would not necessarily be from the same organization where the professor is visiting. Such personnel should be qualified to teach standard undergraduate and/or graduate courses in some phase of aeronautical/aerospace engineering by reason of their education and/or experience. Prior teaching experience and doctorate degrees would not be mandatory, but at least five years of practical experience would be considered minimum. Every attempt would be made to arrange for housing exchanges; each potential exchangee would be given a selection of at least two opportunities. Where there are cost of living or travel deficiencies, the industrial/government concern should make up the differences via a suitable negotiation. In general, each "home" organization would continue paying salary/benefits to its exchangee. At best, industry/government might support both parties in the exchange. Approximately 50-70 exchanges per year are anticipated.

The proposed program benefits both parties and their respective organizations. University professors will have the opportunity to learn of present day problems and new techniques being employed, as well as to learn of changing educational requirements and industry utilization of engineers. On the other hand, industry/government will benefit by permitting their engineers to fight obsolescence, by becoming re-acquainted with detailed technical disciplines in their area of work by means of teaching the subject matter under an updated curriculum.

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* or two, at most.

Industry/government will be provided with lists and vitae of faculty desiring to work in the fields contained in their engineering departments. They can thus make selections which could permit direct replacement of their visiting engineer, or could select a faculty member skilled in some area for a specialized assignment.

Initiative 2 - Students-in-Industry

It is proposed that AIAA act to establish the principle that every Aero student (who maintains a passing grade point average) in an accredited B.S. curricula be afforded the opportunity to work in industry/government during the summer between the junior and senior years. This work would be considered part of the educational process, and students so employed could be given appropriate academic credit. The students so employed would be paid normal "co-op" wages by industry, but the students might pay for their transportation to and from the university and the site of their summer jobs, unless unusual distances or circumstances were involved. Such complications would require negotiation. The work assigned should provide maximum possible augmentation of their classroom education. The benefit to the students would be for all of them to find out what industry is really like. The benefit to the company should be a reduction in their normal recruitment program expense. It is estimated that, in the next few years, approximately 1500 such summer jobs would have to be found. It is suggested that AIAA act as a "clearing house" to match industry billets with student desires. It is suspected that the placement services of most universities could bear the brunt of the actual work involved. If possible, some method should be evolved to permit both students and participating companies to have some right of choice, so long as this does not lead to "shutting out" of lower grade point students. Note that this proposed program should not be confused with the normal co-op program that many Aero departments now share with industry. Regular co-op students would not be expected to participate in this program.

Initiative 3 - Curriculum Development

It is proposed that AIAA work out an agreement with its corporate members and other possible industry/government organizations to arrange industry/government alumni or other knowledgeable engineers to periodically visit their Aero degree-granting department alma maters to participate in curriculum review/revision studies. Such visits, to be arranged by the Aero degree-granting departments, would be of one to two days duration and would occur perhaps once a year, but most likely once every two or three years. Each Aero degree-granting department (there are about 59 throughout the country) could request three or more of their alumni, representing a cross section of organizations and expertise, to participate at such meetings. Visit expenses would be paid by the visitor's industry/government organization.

The purpose of such a meeting is to obtain the advice of practicing engineers on the needs of industry in attacking modern problems. The university staffs are generally too sheltered to be keenly aware of changing industrial requirements and engineer employment assignment practices.

Again, the benefit to industry is that they will help shape the education of their future employees. The visitors, being alumni, will take more than a passing interest in this work; indeed, it should be considered a duty to the profession and will supplement, by detailed inputs, the guideline work done by ECPD* accreditation visits. Results may even cause revision of ECPD general criteria. The universities will gain by the assurance that they are providing relevant educational services.

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* Engineers Council for Professional Development - the organization which accredits Aero degree programs utilizing criteria and instructions developed and approved by the AIAA.

Initiative 4 - Surplus Materiel

It is proposed that a methodology be established such that Aero departments could be given "first crack" at pertinent facilities and/or equipments that are about to be surplussed by industry/government, thereby short circuiting the painful and mostly "lucky" route whereby such information now becomes known. Through a clearing house approach, industry/government could maintain and disseminate listings and descriptions of aerospace type laboratory, research, and instrumentation equipments that will become subject to the surplus procedure.** The departments, in the meantime, would forward updated "shopping lists" to the clearing house. Additionally, the clearing house might publish listings of equipments subject to acquisition by gift or sale. Allocation would have to be impartial, perhaps based on date priority of "shopping lists" on hand or by arbitrarily seeing that the "wealth" is spread. Such a procedure would prevent "junking" of "valuable" materiel by mistake and should permit a tax write-off to industry. It could further preclude the payment of "finder's fees" to State surplus property offices. Industry/government might be additionally willing to provide financial aid in packing/shipping (especially for substantial facilities) and for technical assistance, where required.

ACKNOWLEDGMENTS

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REFERENCE

1. Brodsky, R. F.: A Survey of Aerospace Education in France. American Society for Engineering Education #15-5, ASEE Annual Meeting, Troy, N. Y., June, 1974.

** Or could be made available on bailment or long-term loan.

ADCA

- AEROSPACE DEPARTMENT CHAIRMEN'S ASSOCIATION
- ~ 59 MEMBERS
- MEETS TWICE A YEAR
- ACCOMPLISHMENTS
  - ENROLLMENT TREND FACT-FINDING
  - BROCHURE DISTRIBUTION
  - STAND ON ECPD "ADVANCED ACCREDITATION"
  - THESE INITIATIVES

Figure 1. - ADCA description.

THE PROPOSED INITIATIVES

- PROFESSOR/ENGINEER EXCHANGE
- STUDENTS-IN-INDUSTRY
- ALUMNI AID IN CURRICULUM DEVELOPMENT
- ASSURED EQUIPMENT ACQUISITION

Figure 2. - Initiatives in petition.

UNIVERSITY/GOVERNMENT/INDUSTRY RELATIONS IN AERONAUTICS

By George S. Schairer
The Boeing Company

I will start my comments by describing the role that I expect universities to play in aeronautics. Certainly, the first and most important role of the university in aeronautics is the training of our young people. I expect our universities to train these young people to think clearly about engineering matters, to understand the fundamentals of the engineering way of life, and to help them get started finding their niche in the world. These students may end up doing engineering or business or sales; and they may develop products, conduct tests, or do research. I expect the universities to give those students who are likely to come to industry a good idea of what to expect in the industrial world. Equally, I would expect a student who is going on to do research or work in a government laboratory or agency to have some idea of what he will find when he gets there. The same goes for a teaching career. I do not expect the university to train the student in the job he is going to find himself in after he graduates. I think that task lies with his employer and after he is hired.

There is a second but very important role that I expect of the universities. This is the development of our fundamental understanding of aeronautics. It seems to me that over the years the majority of our knowledge of the fundamental processes of aeronautics came from the people working in the universities, both faculty and students. I believe that the future of aeronautics is highly dependent upon a continuing flow of new knowledge, both fundamental and applied. Most of this is going to come from the universities. I doubt that either industry or government laboratories could dream of replacing the role of the university in this research matter. I think it is terribly important that the universities be operated in such a way and financed adequately to permit them to continue with their major role in research. Furthermore, I believe that the conduct of this research by students is one of the most important ways in which the student receives his education.

We have been asked to answer four questions about the effectiveness of the relations between the universities, government, and industry. In answering, I will try to relate to the two important matters of education and research. Are the relations between us satisfactory and can they be improved? My personal feeling is that things have been going quite well, and the universities are training some very able young people and also are doing some very fine research. They are attracting some fine talent and are making good contributions to the development of these students. I think things are going very well; but -- as an engineering student I was taught to look at everything I came to and examine it to see if it could be improved. I remember when I first learned to fly, I marveled at the design of the stabilizer jackscrew which was used on the small biplane. It seemed to be very satisfactory, but, as a budding young engineer, I had been led to believe that it was my task to examine it critically and see if I could contribute anything to improve it. This question went through my mind many times during the period when I was learning to fly, and it wasn't until many months later that I began to see ways this stabilizer jackscrew could possibly be improved. Through the years since then I remember that experience as one of the fundamentals of what engineering is all about. The engineer must always look at what he has and see how he could improve it to do better. So, here goes with some of the thoughts I have about how the relationships between industry, government and universities could be improved. I think they are pretty good, but as an engineer it is my task to see if I can make some contribution to making them better.

I deplore the anti-technology world we've been living in for the last few years. I don't pretend to understand how it came about. I think the engineers more than any other professional group hold the keys to solving many current national problems, such as, inflation, pollution, transportation, and defense. I think that it is high time that our political leaders came to realize this. They should put their shoulders behind the wheel of getting renewed and stronger programs of government support for the training of engineers and the conduct of engineering research. There are some improperly conceived and also some inadequately described programs which brought the Mansfield Amendment upon us. We all must share in the responsibility for having had it imposed upon us.

However, I think that it is terribly important that we reverse the trend. The various government agencies that support the universities must be freed to use a very liberal interpretation of the Mansfield Amendment and other such limiting administrative procedures. For the life of me I cannot understand the rationale that caused the Haystack Program to be separated from the Department of Defense. To me the Haystack Program is all too comparable to the Isotope Research Program that I knew as a young man. The Isotope Program grew into the Nuclear Weapons Program. Our future is dependent upon new ideas and any administrative procedure that intentionally narrows the search for ideas or directs people away from those subjects in which they as individuals can make the greatest contribution is likely to stifle our society and make us noncompetitive in the world of defense, trade and economics. To me the future of the United States is vitally dependent on getting rid of any narrow interpretations of the Mansfield Amendment. We must all work to see that this is accomplished. The future of our nation depends upon new ideas and bright new engineers to apply them.

Of almost equal importance and much along the same line, I feel that too much directed research in a university, as directed by a government or industrial financial sponsor, is likely to be very unhealthy for our future. We must draw out our students and our research-oriented faculty to cause them to find our future; and certainly telling somebody what to look for is a pretty risky process when you are hoping they will find something that you don't know about in the first place. I'm not all negative on directed research since it provides an excellent communication tool by which the researcher can know more about the world in which his ideas might be used. I wonder if the financing by government should not be about equally divided between grant money and directed research contracts with specific goals in mind. Here again, we have some people in Washington who have different views and think that the public supports them in these different views. I think it is most important for the United States to get back to a more balanced and more liberal approach to the funding of engineering education and engineering research in our universities. I really don't think the public at large has ever supported the restrictive policies that we see so often today.

I am sure that one of the big problems of running an aeronautical education program in a university is that of finance. I'm sorry to say that I see no way in which industry can be a substantial source of the necessary funds. The bulk of the funds to support aeronautical education must come through government support, and we must all work towards the end that our government agencies have workable procedures for liberally financing our aeronautical schools.

The next subject I come to is that of communication between universities and the aerospace industry, the government agencies which buy aeronautical products, and also the airlines. It is most important that there be constant good communication among all these parties and, on the whole, there is; but, just like with the stabilizer jackscrew, I think we can find ways to do better. One place where I think we have done some backsliding is in the summer programs for employment of university professors and students in industry. Industry has been hard pressed financially and have had to cut back in their employment. All too often when the summer season rolls around, industry finds it convenient to decide that they don't want to have any professors or students around for the summer. I think this is a terrible mistake. I hope that industry, and Boeing in particular, will be able to do better in the future and have a lot of professors and students working in our industrial climate each summer. We should have more professors on sabbatical leave working in industry. Both faculty and students will see first hand and very clearly what industry needs, if they spend some time in our midst. We must help this process along.

This conference and the many others that are conducted by NASA, DOT, AEC, and the military services appear to me to be most healthy and our current best way of being sure that we all know each other, talk to each other, and help each other in this process of strengthening the universities.

SUMMARY OF PANEL ON UNIVERSITY/GOVERNMENT/INDUSTRY RELATIONS

By Harold Liebowitz
The George Washington University

Panel Chairman

Speakers:	Panel Members:
Kenneth Lenzen	Robert Howe
Robert Brodsky	David Ellis
George Schairer	John Nicolaides
	Arnold Ducoffe

(1) Additional fundamental research support should be made available by NASA at the Headquarters level, as well as at the laboratory directors level. It is also important to continue supporting research at the program manager levels.

(2) Closer working relationships should be implemented by NASA/Government/University through joint research and educational programs like JIAFS and ICAS.

(3) A viable joint recruitment program by NASA, University, and Industry should be started at the high school level to interest students to enter the challenging and rewarding field of Aeronautics. Joint open house programs should also be held.

(4) Work-Study aeronautical opportunities as well as related student cooperative and faculty positions should be listed by NASA, Industry, and University in one publication like an AIAA Journal. A joint committee should be established for this purpose. This committee could also act as a clearing house to advertise and initiate exchanges of personnel.

(5) Universities should increase their number of joint adjunct and research appointments to include more of the engineers from industry and NASA.

(6) The surplus equipment from NASA and Industry should be made more readily available to the aeronautical departments in this country.

(7) NASA/University Conferences should be held more frequently to provide opportunities for the aeronautical community to get together and exchange viewpoints.

(8) NASA should implement a research program particularly for young investigators starting in the field.

(9) A positive joint statement by NASA and industry should be made on the importance of the university and college curricula in aeronautics and astronautics for this country.

PANEL II
UNIVERSITY RESEARCH IN AERONAUTICS

UNIVERSITY RESEARCH IN AERONAUTICS

By John E. Duberg
NASA Langley Research Center

Past progress in aeronautics was characterized by the requirements to solve difficult technical problems of aerodynamics, structures, and propulsion in which the physical bases of the phenomena were not well understood or a high degree of invention was required. The trail lead somewhat simply from subsonic and transonic to supersonic and hypersonic flight.

Today's challenge relates on one hand to the more accurate and detailed analysis of the physical phenomena in these several subdisciplines of aeronautics in which the large-scale computer is conceived of as a more economic tool to supplement and to replace the more traditional wind tunnels, structures and engine test laboratories. On the other hand there is the challenge to integrate this detailed knowledge into aircraft systems that are safe, socially acceptable and can be operated within existing or evolving airways and airports. The large design teams responsible for these efforts are made up of individuals who have been educated in the discipline of many of the engineering departments of the universities and are contributors in their own specialties. But when one looks to the leadership of these groups, in general it is the graduates of aeronautical or aerospace departments who have the ability and are given the responsibility to synthesize the elements into a final design. Again the large-scale computer is recognized as an aid in the synthesis and optimization of aircraft design.

In more recent times there has been an increasing utilization of electronics in the control of the dynamics of the airframe and for aid in the control of the vehicle which further complicates the design process. To do forefront research in these fields can involve substantial investment in facilities such as computers and instrumented aircraft with which the NASA research centers are supplied. Of concern here is: How does one make the best match between these capacities and the university and industry? An increasing number of administrative tools have been developed to permit university staffs and their graduate students to participate at NASA Centers in their programs, and a modest beginning has been made to include industry personnel in these programs.

The more conventional of these is the National Research Council of the NAS-NAE program sponsored by the NASA Office of University Affairs which brings post-doctoral associateships into the NASA Centers for a year's activity but extendible to a second year. Although this program has been attractive to scientists, especially from abroad, it is not limited to such individuals. Langley Research Center would welcome a greater participation in this program of engineering faculty members from American universities who are United States citizens.

Two special institutes have been established at the Langley Research Center for the purpose of exchanging personnel with the academic community. The Institute for Computer Applications in Science and Engineering makes appointments for time periods of a few weeks to several years to individuals interested in exploiting the computer facilities at Langley, which next year, will include a CDC STAR 100. These efforts extend the inhouse effort at the Center which has tended to be concerned with large-scale aircraft structural analysis and design problems and problems in fluid flow. This Institute is under the sponsorship of the Universities Space Research Association.

A second institute more broadly based in its interests is the Joint Institute for Acoustics and Flight Sciences. It is operated by the George Washington University and includes activities in low-speed aeronautics, automated structural design, acoustics and atmospheric modeling. In addition to bringing engineering teaching faculty members to the Center the program also includes research associates and part-time graduate students.

On a more individual and isolated basis, from time to time research grants have been made to universities for research activity in which certain unique facilities at Langley have been required for their execution. Members of the university staffs have then been resident at Langley for the time required to do the experimentation. Our host, the University of Kansas, has frequently been involved in such arrangements.

The Intergovernmental Personnel Act of 1970 has given a new degree of freedom to federal agencies to exchange personnel with state and local governments and with public and private higher educational institutions. Salary arrangements are negotiable and mutual benefits are implied. Most of our experience so far has been exchanges from the Center to universities but the arrangement is well suited to sabbatical leave and one such professor is now at work at Langley.

The long standing arrangement with the American Society for Engineering Education prospers and is our principal means for bringing to the Center university faculties during the summer. The research program provides for individual research effort. A second part, the so-called design effort, assembles each summer a design team of approximately twenty persons to study a large-scale problem. This represents one of the few means at our disposal to provide a multi-disciplinary design team experience to university faculties.

Two activities which provide interesting joint efforts of shared responsibility to do a larger task are worthy of note. One is a joint effort of Ohio University, Princeton, MIT, Langley Research Center and certain private consultants to develop a low-cost general aviation avionics. Current emphasis is on a navigation system based on the reception of the very low radio frequency transmissions of the Navy worldwide OMEGA network. The other is a joint effort of the University of Kansas, Wichita State University, Robertson Aircraft and Piper Aircraft Companies and Langley to produce an advanced wing for a general aviation aircraft.

I hope that this display of a wide spectrum of operating experience leaves you with the realization that our mission to do aeronautical research and development and your mission to educate the next generation of aeronautical research scientists and designers are mutually compatible and that we both can gain by seeking innovative ways to join our individual competencies.

GENERAL AVIATION'S FUTURE NEED FOR RESEARCH

By Malcolm Harned*
Cessna Aircraft Company

As we look into the future one of our principal concerns is improving the efficiency of energy usage. All improvements in this area have a doubling effect, because fuel weight reductions mean overall reductions in aircraft weight, which means further savings in fuel. This places emphasis on the following fields of improvement:

1. Airfoils with improved lift/drag ratios both for low speed and high subsonic (Mach No. = 0.8 to 0.9). Particular consideration should be given to relatively thick sections which make possible a high aspect ratio with minimum weight.

2. Propellers should offer an area of significant potential for improved propulsive efficiency since the most efficient airfoil available today is the 50-year-old Clark Y. We have a variety of parameters to work with considering tip speed, spanwise loading, variation in spanwise section, as well as basic airfoil sections. Of particular value would be configurations which can use direct-drive piston engines, which are the most challenging because of the high tip speeds.

3. Reduction of specific fuel consumption both in piston and turbine engines. Consideration could even be given to alternate approaches, such as the Diesel and Stirling engines. Development of effective means of utilization of exhaust energy certainly offers potential, although it is a real challenge.

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*Presented by Harvey Nay.

Another area of great importance for future research is that of environmental factors including external noise, internal noise and exhaust emissions. The following areas are suggested:

1. Research into needed levels for restrictions on both external noise and emissions. It is very important not to impose unnecessary restrictions because of the penalties in cost and the waste of fuel which would result.

2. Techniques need to be developed to reduce propeller noise for improving both internal and external noise levels.

3. Exhaust noise reduction techniques should also offer potential improvement.

4. Methods for reducing noise transmission into the cabin interior are needed for piston, turboprop and jet propelled aircraft.

Methods for weight reduction are also of substantial interest. Here the opportunity for a research payoff appears to be in the field of materials in obtaining improved elastic moduli, static strength to weight ratios and improved fatigue characteristics. One of the particular areas of promising potential appears to be that of carbon fiber reinforcement in laminated structures, if reasonable costs can be achieved. The application to propellers is of considerable interest, as well as to static structures in high performance aircraft.

There is also one very important safety area that appears to offer potential for research, and that is icing. This is one of General Aviation's most serious safety problems and one which is being solved only by techniques which are costly, heavy and with adverse aerodynamic effects.

UNIVERSITY RESEARCH IN AERONAUTICS

By Holt Ashley
Stanford University

INTRODUCTION

My role in the triad this morning appears clearly to be that of line member of a university aerospace faculty, and I shall attempt to assume that viewpoint with a somewhat higher degree of "purity" than is probably justified either by my own personal body of opinion or by the diversity of my career experiences over the last 30 years.

As to the question of what kinds of activity universities should undertake for government and industry, let me begin by emphasizing the negative and mention what they have not tended to do very effectively in the past. From that low point, let me then move up to what they have unusually well done hitherto and how this might change in the future.

HISTORY

A. In the past universities have not very often done a good job of

- i.) Building and operating large test facilities (the overhead is too high; such facilities tend to be inflexible; and NASA and USAF have really handled this service very well).
- ii.) Designing and (especially) building large aeronautical systems (won't name names except to mention one long-dead fiasco called "Project Meteor" at M.I.T.). Also there are exceptions: small spacecraft such as the DISCOS drag-free satellite at Stanford with Applied Physics Lab, Johns Hopkins University and (I am told) the Doctor of Engineering design projects at the University of Kansas described by Dr. Lenzen.
- iii.) Carrying out large-scale interdisciplinary projects of any kind.

The systematic reasons for these failures are both the ivory-tower isolationism of the typical faculty member and the fact that students get lost in them. When such projects do get under way, they tend to result in the formation of large, decoupled laboratories (JPL at CIT, C.A.L. at Cornell, A.P.L. at Johns Hopkins). Among these the only one I know that integrated well into the educational process was the Draper (formerly Instrumentation) Lab at MIT, and it was wholly disowned by the university on July 1, 1973.

B. Successes have tended to be in applied scientific research in the aerospace-related disciplines, where one or a small group of students can make a contribution within the time constant of a Ph.D. thesis. It's worth mentioning that more than half of Mr. Nay's "fields of improvement" fall, by my estimation, wholly or partly within this category.

I think we professors can be quite proud of what has been accomplished under this banner, and I strongly urge that it continue to be one major focus of our activity, albeit not to the exclusion of innovative experiments. Everyone has his list of favorite examples, but let me cite a couple of mine:

i.) Wallace D. Hayes published the transonic and supersonic area rules in his Ph.D. thesis of 1947 (N.A.A. Rept. No. A.L. 222). Can Dr. Liepmann tell us who supervised?

ii.) A.H. Bryson and his Harvard student, Walter Denham, in 1961-62 told the Navy how to climb the F-4H to M = 1 and 65,000 ft (330 sec. vs. predicted 332 sec.).

iii.) W.H. Durand, Stanford 1918-19, under NACA supports did the first systematic series of tests to establish scaling laws and otherwise learn about parametric effects on propeller performance.

iv.) E.E. Covert and students at MIT built and operated the first working example of a magnetic wind-tunnel-model suspension.

These were all examples of government-sponsored research, and we must again acknowledge the past and future role of governmental agencies in supporting both the students and the useful things they and their faculty advisors do.

THE FUTURE

There are instances - significant but limited to date - of other modes in which universities can do research and develop "new directions for aeronautics." Let me both cite and endorse two examples:

i.) The collaboration with agency laboratories, notably the work of students and staff with NASA centers referred to by John Duberg. We are spoiled at Stanford because of being a 10-minute drive from Ames Research Center. We see a very genuine possibility of using the facilities of Ames as an extension of our small labs, and the personnel as a supplement to our own research advising.

Collaboration efforts include Biomechanics Program (Anliker/Chang since 1968), Joint Institute for Aeroacoustics (Karamcheti, founded last year), NASA/ASEE (Stanford/Ames), Summer Institute and Research Program. Incidentally, Dr. Hans Mark and Dr. Fred Hansen are consulting professors at Stanford.

ii.) Having interdisciplinary research projects between universities and industry/government labs, in the manner so effectively developed since 1972 by NSF RANN program (examples: Ford-R.P.I. on NA/S batteries B-Alumina membranes; U.C.L.A. leaderships of Van Norman dam earthquake analysis; Montana University and others in geothermal explorations).

CLOSING

Let me close with emphasis not just on constructive aeronautics but also on applications of aerospace technology to society and work on domestic societal problems.

SUMMARY OF PANEL ON UNIVERSITY RESEARCH IN AERONAUTICS

By Barnes W. McCormick
Pennsylvania State University

Panel Chairman

Speakers:	Panel Members:
John Duberg	Hans Liepmann
Harvey Nay	Frederick Smetana
Holt Ashley	Charles Cliett
	Edward Rodgers

This session began with a presentation by Dr. J.E. Duberg, NASA Langley Research Center. Dr. Duberg noted the lead which Aerospace Engineering assumes in design groups. He spoke of the special institutes which are held at Langley for faculty, encompassing computer applications, acoustics and flight services.

His presentation was followed with one made by Mr. Harvey Nay, Chief of Engineering for the Cessna Aircraft Company. Mr. Nay spoke of the need to improve energy usage as well as the need for research on other specific items including the lift-drag ratio of airfoils, propellers, specific fuel consumption, direct drive propellers, the utilization of exhaust energy, definition of reasonable noise limits, improving fatigue properties of materials, and icing prevention. Mr. Nay expressed the opinion that the basic role of the university relating to such research should be at the exploratory level.

The last formal presentation for this session was given by Dr. Holt Ashley, Stanford University. Professor Ashley pointed to the fact the universities have not done well in the building and operation of large facilities or in the design and construction of large scale systems. Relating to scale, he felt that universities should concentrate on projects requiring a time duration compatible to that required for a typical Ph.D. thesis. Should the need arise for a large facility, he suggested that the University collaborate with government laboratories and he mentioned several examples where this has proven successful. In closing his speech, Professor Ashley gave a strong endorsement to the future of aeronautics.

Following the formal presentations, comments were offered by four panel members, Professor H.W. Liepmann, California Institute of Technology; Professor F.O. Smetana, North Carolina State University; Professor C.B. Cliett, Mississippi State University; and Professor E.J. Rodgers, Wichita State University.

Professor Liepmann noted that the principal responsibility of the university is to teach. However, he emphasized that involvement in research activities makes for a more interesting teacher. He noted many challenging problems as yet unsolved that should stimulate student and faculty interest. Among these he included the minimum noise from jets, the study of convection by "strange" fluids and electron gas analysis. He stated that "good research is always relevant, poor research is never relevant." He also expressed the opinion that research contracts are often too restrictive and concluded that university faculty should avoid contract monitors or program managers in seeking research.

Professor Smetana felt that a University can efficiently undertake state-of-the-art surveys, theoretical analyses, and projects involving small scale testing. In line with Professor Ashley's remarks, Professor Smetana stated that experimental programs should involve a limited amount of hardware. He also felt that faculty generally need more contact with industry.

Professor Cliett proposed that a national plan for aeronautics be formulated. Such a plan could smooth out the peaks and valleys which have been experienced in the industry in the past. He also felt that such a program could improve our political image. He somewhat reiterated the remarks of the previous speakers, expressing the opinion that for universities, discrete research programs are better than large involvements. He felt that such programs should constitute a mix of hardware and theory. He also expressed the opinion that we need more joint programs with industry.

Professor Rodgers noted that University criteria for promotions and the like have inhibited design activities on the part of faculty since weight is given primarily to papers generated as a result of research. He felt that the engineering image as a scholarly and innovative activity needs to be improved and pointed to the old cliche regarding the "scientific success versus the engineering failure." With regard to the other points and being the last speaker on the panel, Professor Rodgers could only agree in principal with most of the comments of the previous speakers.

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PANEL III
CURRICULUM FOR MODERN AERONAUTICS

CURRICULUM FOR MODERN AERONAUTICS

By Leonard Roberts
NASA Ames Research Center

I am very pleased to have the opportunity to give you some personal views on the questions posed for this session on the Curriculum in Modern Aeronautics. I should say at the outset that they are the biased views of a Director of Aeronautics at a NASA Research Center, looking at the University from the outside. These views are tempered, to a degree, however, by some teaching experience at MIT and the University of California. Having characterized myself let me turn to the questions that have been posed.

WHAT KIND OF STUDENTS SHOULD BE DEVELOPED THROUGH AERONAUTICAL ENGINEERING EDUCATION?

With respect to the education of undergraduate students: I would first require them to be well grounded in the traditional disciplines: physics, applied mathematics, continuum mechanics, chemistry. Second, I would want them to be familiar with some practical tools: design synthesis, the use of computers, engineering laboratory techniques and drafting practice. Third, in their senior year it should be required that they take some specialist courses: aerodynamics, electronics, structural analyses, for example. This undergraduate education should be adequate to start the student in a professional career in aeronautics or in another engineering field.

In his graduate education he should concentrate on special courses in the aeronautical engineering subjects but also take sufficient additional courses to permit him to place his specialty in the broader framework of aeronautical engineering. I don't believe that so-called "systems analysis" should be emphasized even in graduate school. I believe "systems analysis" shoulld come later in an engineer's career when he has enough experience to recognize the shortcomings as well as the values of this subject.

What kind of student does such an education produce? He is a student with enough basic education to give him *mobility* within the engineering profession and enough *perspective* to know where he fits. A corollary of this view is that it does not require very much *specialist* undergraduate education to prepare a student for a successful career in aeronautical engineering, recognizing that he will engage in several years of on-the-job training after graduation.

TO WHAT EXTENT SHOULD AEROSPACE ENGINEERS BE PREPARED FOR DIVERSITY AND CHANGE?

I don't believe it is likely that there will be a *predictable trend* in the level of employment in aeronautical engineering in the foreseeable future, or that the focus of aeronautical development will stay constant. There may be a rapid increase in the demand for aeronautical engineers by 1980 as we approach the end of the useful life of current aircraft and the retirement of the engineering population educated in the 1940's; on the other hand that demand may not materialize. The focus of aeronautical technology in the recent past has changed from increased speed to reduced noise to fuel conservation, each involving different specialist competences. And the focus may change again just as quickly to the technology that minimizes development cost, for example.

I would say that the industry will continue to have fluctuations in demand for engineers and changing needs for expertise. So "be prepared for diversity and change" is the advice I would give to the prospective aeronautical engineer.

TO WHAT EXTENT SHOULD THEORY BE EMPHASIZED AS OPPOSED TO PRACTICAL ENGINEERING AND DESIGN?

The answer is "yes." Clearly we need both. I would like to express a couple of pet concerns, however.

I do have a concern regarding thoeretical methods, in that they are frequently over-elaborate and lose sight too quickly of the physical problem or phenomena they are trying to represent. And this tendency is aided and abetted by the unintelligent use of high speed computers, wherein the answer is simply an array of numbers rather than an increased understanding of the problem. I should make it clear, however, that I am very much in favor of the imaginative use of computers as described by Dr. Chapman in his paper.

I also have a concern in the areas of practical engineering and design. The drafting engineer seems to be a dying breed. Engineers are coming out of school with no training in drafting. Here, I think the computer should be introduced so that the engineer can be relieved of the more mundane tasks, which a computer-driven graphics plotter can do, so that he can spend his valuable time on the more intellectual task of providing a good design.

A SUGGESTION FOR NASA/INDUSTRY/UNIVERSITY COLLABORATION

I would like to end my remarks with a suggestion on what NASA might do to augment the University curriculum, recognizing that, while NASA is not in the business of education, NASA necessarily is in the business of training aeronautical engineers.

In times past, when NASA was NACA, the agency took pride in pointing out that many of the engineering leaders in Industry, and the Universities, had passed through the NACA laboratories. It was an accepted pattern that aeronautical engineers received part of their training in the NACA. Perhaps NASA, the Industry and the Universities should again establish such a pattern along the following lines:

(1) NASA sponsors a student in his senior year through a small grant.

(2) Upon graduation the student spends two years at a NASA Center as part of a NASA/Industry/University Training Fellowship with the understanding that he will have,

(3) Assured employment with an industrial company or an assured place in a graduate school for an additional two years.

Such a program need not involve large numbers of people to be effective; for 40 people placed each year into such a program the total cost would not exceed one million dollars per year, or less than 1% of NASA's Research and Development budget in Aeronautics.

This integrated approach to education, training and employment would have several advantages:

It would be a mechanism to assure a continuing strong relationship between the Universities, NASA, and the Industry, at the grass roots level.

It might be a mechanism for smoothing out the variable demand for aeronautical engineering graduates. NASA Centers would be used as a "capacitor," a "flywheel" during periods of lower employment opportunity.

It would provide a cadre of people, within Industry and the Universities, who would be sufficiently familiar with NASA facilities to participate in the conduct of joint research programs with NASA.

There are strong indications, in my view, that we will need some arrangement of this kind in the future. The industry needs it to better prepare for the next generation of aircraft which must incorporate new technology to be competitive. The university needs it to revitalize itself and to provide the context for its disciplinary education. And NASA surely needs it. It needs to have a new injection of enthusiasm; it needs to have a few more innovative people to try out new ideas. NASA needs to have young people pass through its system again.

CONCLUDING REMARKS

I very much appreciate the opportunity to express my views on this subject. I hope they may stimulate new ways of thinking about NASA as a device to improve upon and augment the Curriculum in Modern Aeronautics.

ENGINEERING EDUCATION FOR THE 80's; A SPECULATION

By Eugene E. Covert
Massachusetts Institute of Technology

SUMMARY

The development of a course of study is briefly examined from two points of view. The first represents the background that would seem to be needed for a fledgling engineer upon his entry into the engineering profession and would allow him to complete successfully his on-the-job training, or engineering internship as it were. The second represents that which must be provided on the basis of the students background from secondary school. It is suggested that a course of study viewed in this way is never fixed, but rather evolves continuously. A particular evolving course of study is briefly discussed.

DISCUSSION

I am appearing here to discuss some aspects of Engineering Curriculum Development with mixed feelings. While I am always willing to expound my beliefs, I am acutely aware of the central issue of objectivity as opposed to subjectivity. I know of no satisfactory way to measure the effectiveness of a curricula. In fact, I know of no way to even plan and conduct an objective experiment that will yield quantitative data on the "goodness" or "badness" of a curriculum.

Before discussing either a general or a particular curriculum, I want to make several statements that provide you with some insights into my personal prejudices. I am convinced that it is simply not possible to teach anyone to be a professional engineer within any formal course of study. Armed with a Bachelor's degree in engineering a fledging engineer is prepared to start on-the-job training, or internship and residency, if you prefer. Then in the next three to seven years the fledging engineer becomes a professional engineer.

Thus I envision engineering education in three steps. The three steps may be represented as three blocks in a block diagram, Fig. 1. The earliest block is high school; the next is college or university; and the last is the internship or on-the-job training. There are feedback loops in this process. For example, the professional societies, like the AIAA, cooperate with the Engineers Council for Professional Development (ECPD) to arrange for accrediting. However this feedback is in the form of policy statement rather than a detailed guide to subject content which is as it should be. There is also feedback to the high schools, but this feedback is relatively weak. Note the time constant of this loop is very long, in excess of ten years. Thus, as a dynamic system the educational process is quite sluggish in comparison with many other social processes.

For purposes of discussion it is convenient to separate Engineering curriculum into two classes. These two classes may be termed discipline oriented, or goal or mission oriented. A discipline oriented course of study is just what the term implies. One single discipline dominates the subject matter. This seems to be the case in Civil Engineering, Electrical Engineering and Nuclear Engineering. However, Marine Engineering, more or less, and Aerospace Engineering are almost completely goal or mission oriented. The latter two areas of study are focused on a vehicle. These courses of study are more or less of a general engineering education in that the student learns some structures, fluid mechanics, propulsion, automatic control and electronics. Further the student is taught to apply these disciplines to problems associated with design, operation and perhaps maintenance, of aircraft or spacecraft. These applications provide the focus and in many cases the motivation for this broad range of study.

I have one further comment related to curriculum development. Many of us are convinced that the large scale automatic computing machine is here to stay. Consequently, we feel the ability to develop numbers is of less importance than it was formerly. But the ability to have an understanding of the physics of what one is doing and to convert this understanding into an estimate that may be accurate for from 5 to 10% is of increasing importance.

In this way the significance of the computer generated numbers can be more accurately accessed. Equally important, engineers must have a background that allows them to visualize interactions that have to be assumed away for purposes of analytical simplicity. This kind of background requires as much laboratory work as possible.

With this introduction we can discuss how one develops a curriculum. First we must have some understanding of what our students have learned in high school. This provides us with a starting point. Thus we must have an idea of what we must add to realize our end point. Further, the end point, the graduating senior will be conditioned by the career development following his or her entry into the profession. When we try to imagine all the possibilities involved in career planning, we quickly conclude that no single engineering department could offer a properly detailed course of study. Further, it is not likely the engineering departments will ever come to an agreement in which one teaches only those students who will go into production engineering, while another will teach only detail design, and a third will teach preliminary design aerodynamics and so forth. In any case this hardly seems desirable.

On the contrary, since the first engineering job is widely regarded as an apprenticeship, it seems to me that the course of study should be aimed at preparing the student to be successful in a wide variety of apprenticeships or of on-the-job training situations. This apprenticeship might change as the graduate's interest can change, the state of the economy can change or the national interests could change. In short, we want our students to learn how to learn. Hopefully, they will ultimately be observant enough to see what they should learn, but we should help them in this regard too, as best we can.*

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* Note that what to learn varies widely as one progresses along in one's career. At each level in a career many engineers wish they had had a different course of study, one more suited to their current needs. Of course, they have forgotten their earlier feeling about a different list of subjects. This point is one which can start vigorous but pointless arguments.

The sequence of subjects in the course of study should provide the students with a clear idea of what we think is important. Further we must teach them how to formulate and solve a problem in a quantitative sense. We must provide the students with the opportunity to try to fit these solutions together in a more complex problem. A course in which the students carry out a preliminary design is ideal for this latter purpose. We must provide several real world situations in which the students come to appreciate the limits of analysis, as well as its power. If we can bring this off we should graduate students who have some useful vocabulary of both words and technical tools. We would like to give a young person an internal sense of standards and competence and also give them self-confidence. To satisfy a final prejudice, mentioned earlier, we try to teach these students that a four foot high pile of computer print-out is a poor substitute for solid understanding.

I should like at this point to be able to offer a prescription to meet all these ends but I can't. I am not sure that such a course of study exists. Even if it does, I don't think it will meet all these ends five years from now. In short, it may well be that the proper course of study is a continually evolving course of study. If that is true, feedback from the user of our product is of vital importance. This is particularly true in terms of the time constants that are involved.

I will, however, describe the evolving course of study I am associated with. I will try to make it clear why we feel that what we do gives a chance of meeting the goals I described earlier. First let me briefly mention our approach to the Sophomore year. We are presently teaching the four sophomore subjects, Solid Mechanics, Thermodynamics, Aerodynamics and Dynamics in a cohesive unit. We try to avoid teaching in little logic tight boxes. This allows the homework to be more interesting, at least for us who grade it. We use all of each other's materials in the homework and in the laboratory activities. The laboratory exercises include some set up and some design and fabrication of small parts for the experiments. In this way the students are faced with real but simple problems in a supervised environment. The students initially find this a little upsetting, so we provide a "Commons Room" where the students can go for supervised homework sessions, preparation of laboratory reports, study for other subjects, and even get to know each other a little better. While it is hard to prove or disprove this approach, the students in the upper class who have had this combined course for sophomores, which Jim Mar dubbed Unified Engineering, seem to be much more self-confident and more self-assured than we would expect from earlier experience.

Our complete course of study is listed below in the left hand column, and some comments on its value are listed in the right hand column. A more succinct description is shown in Figure 2.

Subjects	Comments
Differential and Integral Calculus Ordinary Differential Equations	Mathematics is a useful tool. The increasing use of the ideas of closed loop systems really requires some knowledge of Differential Equations.
Three semesters of Physics including Electromagnetism and vibration and wave propagation	Physicists are superb at isolating the central issues and analyzing the approximate situation in detail. Learning and understanding this method is valuable to engineers, particularly as their responsibilities increase. This skill is best sharpened by continual practice. It is not just luck that most good engineers are skilled estimators.
At least one semester of Chemistry. We prefer Chemistry of Materials, with a Lab.	Knowledge of materials is a corner stone of engineering. Further this material is semi-empirical and provides a welcome contrast to Physics and its heavy concentration on analysis.

One semester of modern circuit analysis (Electrical Engineering). An elementary laboratory is essential here, too.	As electronics becomes even more ubiquitous and more reliable, it becomes increasingly important to have enough vocabulary to discuss electronics intelligently. Further most students find the knowledge useful in other laboratory activities that arise in their course of study.
One semester each of Dynamics, Solid Mechanics, Thermodynamics and Aerodynamics. Laboratory is important here. Initial laboratory work is pretty much canned. Later in year more flexibility is allowed.	These basic science subjects are best taught in the sophomore year but within the frame work of Aero Engineering. The students learn elementary problem solving here by means of Aero and Astro examples. These provide a sense of size of several important quantities. Simple, well-thought-out laboratory work helps to keep the proper perspective between analytical work with its necessary assumptions and actual processes. We closely supervise a design of a part used in one experiment. The students build this to a time schedule and use it in the experiment.
Three advanced technical subjects out of the four listed below: Physics of Fluids or Aerodynamics, Gas Turbine or Rocket Engines, Automatic Control or Navigation, and Structures. (Note: the students can take all these subjects if they wish)	These subjects provide further experience in obtaining understanding and solving problems associated with nearly real, complicated devices or subsystems. The emphasis is more on the type of hand computation that would allow the students to judge the results of a detailed and complicated

	numerical analysis any automatic computing machine could produce. This is easy to describe and difficult to bring off well.
One semester Project Laboratory	Here the student must build something and take data to show whatever he/she built works more or less as hoped and planned. We hope again here to provide balance between analysis and the actual world. We have had some great projects and some lemons. Everybody learns that it is easier to talk about doing their project than it actually is to do it. One difficult problem is to keep the projects cut down to a proper size. Hopefully, the students learn that it nearly always takes a half hour to do a five minute job.
One semester of Preliminary Design, either Aircraft or Spacecraft	The real educational value of this subject seems to me to be the synthesis of all the separate disciplines into a single task. It is this kind of synthesis that we feel helps to distinguish Aero and Astro from Mechanical Engineering. We hope, too, to provide the students with a vague feel for how decisions made several weeks earlier can force one into a tight position now.

While this course of study does not contain any reference to humanities, it is important for engineering students to have eight semesters of this type of classwork.

Note this course of study can be applied to cooperative as well as continuous study.

In summary, this course of study is evolving. It may be that this in and of itself is important. We teach much more than we realize, and perhaps the fact that we are interested enough to continue the evolution helps to motivate the students to work more effectively in their studies.

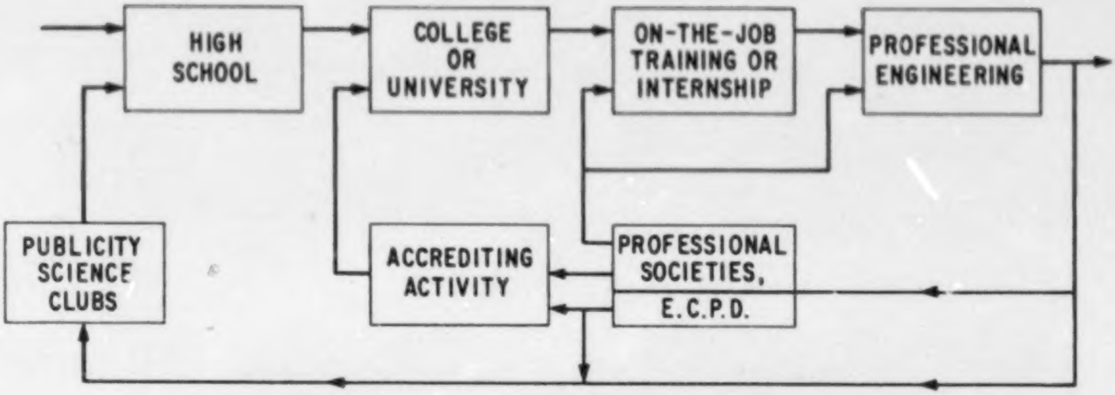
HIGH SCHOOL
COLLEGE OR UNIVERSITY
ON-THE-JOB TRAINING OR INTERNSHIP
PROFESSIONAL ENGINEERING
PUBLICITY SCIENCE CLUBS
ACCREDITING ACTIVITY
PROFESSIONAL SOCIETIES,
E.C.P.D.

Figure 1.- Engineering education block diagram.

	CLASSROOM SUBJECTS						
TECH GOALS	MATH (INCL. O.D.E.)	PHYSICS PART. MECH. (E & M) (VIB & WAVES)	CHEMISTRY OF MATERIALS	UNIFIED ENGINEERING	ADV. TECH SUBS.	PROJECT LAB	DESIGN
SKILL IN USE OF MATHEMATICS	✓	✓		✓	✓		
DEVELOPMENT OF SENSE OF EMPIRICISM			✓	✓		✓	✓
DEVELOPMENT OF ANALYTICAL SKILLS	✓	✓		✓	✓		
DEVELOPMENT OF PROBLEM SOLVING SKILLS	?	?	✓	✓	✓	✓	✓
DEVELOPMENT OF FEELING FOR SYNTHESIS				✓		✓	✓
ORAL PRESENTATION PEER JUDGEMENT REPORT WRITING				✓		✓	✓

Figure 2.- Relation of classroom studies to desired learning.

WHAT KIND OF STUDENTS SHOULD BE DEVELOPED THROUGH AERONAUTICAL ENGINEERING EDUCATION?

By Richard B. Holloway
The Boeing Company

SUMMARY

The state of the art in aeronautics is greatly advanced over what it was only twenty years ago. Commercial air transportation has reached a level of safety, service, speed and reliability undreamed of by its pioneers. Military aircraft have achieved very high values of speed, range, payload, and energy maneuverability.

While emphasis in aeronautical engineering twenty years ago was strongly toward improving airplane performance, today the emphasis is shifting toward the broader, more difficult, problem of achieving good performance at minimum cost, or perhaps even compromising performance to obtain a lower initial and/ or life-cycle cost, while at the same time assuring minimum impact on the environment.

Continuous change in priorities and requirements is one of the most stimulating characteristics of aeronautical engineering. How should the students of today and tomorrow be trained differently than their predecessors so that they can best be prepared to cope with continuing change?

This paper postulates that future generations of students must first be problem solvers, with all that that implies. They must be sensitive to cost implications in their problem solving. Environmental considerations and conservation of natural resources will be factors throughout their careers. Skill in planning and organizing an engineering job will be more of an asset than ever, and superior communications abilities will be of great importance in getting the job done.

INTRODUCTION

When one accepts the task of discussing "What kind of students should be developed through aeronautical engineering education?" he might begin by listing those areas in which current aeronautical engineering graduates are lacking. The problem with that approach, if indeed it should be called a problem, is that today's aeronautical engineering graduates are the best we in industry have seen, and they keep getting better. Their capabilities seem to improve with each succeeding class.

So instead of telling you what's wrong, let me tell you some things that are right, by describing some of the attributes and characteristics that our best young engineers seem to have in common. Not surprisingly, the best characteristics are not necessarily developed by the formal curriculum, but instead are brought about by the attitudes of the faculty and their ability to bring "real-life" engineering into the classroom. Another non-surprise is that students who get involved in introductory engineering work outside the classroom, by acting as aides in research projects and by undertaking projects for engineering displays, student technical societies, etc., are in my estimation strengthened considerably by their experiences, and become better engineers because of it.

Over the years there have been some characteristics which have seemed to me to be associated with those young engineers who have gone on to become our best contributors. These qualities are the same as those which make good supervisors and managers. Fundamentally I believe our best engineers are:

- Problem solvers
- Planners and organizers
- Communicators
- Professionals

PROBLEM SOLVING

Graduate engineers should be prepared to think for themselves. They should be exceptionally well trained in scientific and engineering fundamentals and understand and know how to apply the scientific method to the identification and solution of practical problems. Here is where a young engineer who has helped in a University level research project has an advantage over one who has not. In working on a research program, even if only in a small way, he has experienced the application of his training to the solution of a "real-life" problem, and has been matured by the process.

I emphasize the necessity of sound training in fundamentals - industry takes care of its own training in specialties. In some cases industrial emphasis on subject specialization tends to create barriers to communication between disciplines, barriers which are very hard to tear down. Specialization prior to leaving school would be even worse. Ideally an aeronautical engineer should be flexible enough to be able to work in design or analysis in structures, aerodynamics, systems, etc., but of course this ideal is seldom obtained. A modern trend in engineering is toward many interdisciplinary types of study and effort. The day of strict subject specialization may be nearing an end and we may soon find the biggest demand is for engineers who can find their way around in several allied fields.

To be a successful problem solver a young engineer should know how to systematically synthesize several solutions to a problem, then analyze the proposed alternatives to determine which one is most nearly optimum under a given set of constraints. He must know (or learn) how to evaluate such factors as cost and timing in determining the "goodness" of a proposed solution. Evaluation of alternatives today involves environmental impacts, and "social acceptance" factors which the young engineer of today will have to consider throughout his career.

Our best young engineers today have been given an understanding by their professors of the necessity for using common sense in their work. Because in recent years engineering education has tended to become scientifically, rather than design oriented, some new engineering graduates lack an appreciation of the importance of the "practical" side of engineering. By that I mean the concept of designing something, building it (or a model of it), and testing it to see how well it works.

In aircraft design we have gone to extreme lengths to develop improved methods of analysis and synthesis, utilizing the tremendous capability of modern digital computers, to conduct design studies which would have been impossible only twenty years ago. I feel that to some extent use of these large, complex, computer programs prevent younger engineers from developing an intuitive "feel" for the problem under consideration. This is particularly true if the program user had nothing to do with constructing the program. The great structural designer Pier Luigi Nervi commented, "The pre-eminence given to mathematics in our schools of engineering, the purely analytical basis of the theory of elasticity, and its intrinsic difficulties persuade the young student that there is limitless potency in theoretical calculations, and give him blind faith in their results. Under these conditions neither students nor teachers try to understand and to feel intuitively the physical reality of a structure, how it moves under a load, and how the various elements of a statically indeterminate system react among themselves." (Reference 1). He further noted, "It would be absurd to deny the usefulness of that body of theorems, mathematical developments, and formulas known by the rather inaccurate name of "Theory of Structures." But we must also recognize and state unequivocally that these theoretical results are a vague and approximate image of physical reality. We come nearer to this reality only by adding the results of experiments to the mathematical results, by observing the actual phenomena, by establishing a conceptual basis for these phenomena, and above all by understanding intuitively the static behavior of our works." (Reference 2).

PLANNING AND ORGANIZING

Our best young engineers learn quickly how to break down an assignment into sub-tasks, which when accomplished in sequence will provide the needed solution. They know that to understand a technical job all the way through, they must understand its elements. It is this ability to plan and organize in a systematic fashion which often leads a good engineer into a supervisory position.

Much of the ability to organize a job is developed after the young engineer leaves school, but the basis for planning is the scientific method, which should be fundamental to any university engineering curriculum. Professors today should lead their students beyond the belief that the only correct answer to an engineering problem is the one in the back of the book. The fact that in practice there are often several satisfactory answers to a given problem, and that there are many alternatives which must be evaluated, should be brought home to the student throughout his formal education.

Airplane design classes and participation in research projects both offer excellent opportunities to teach job planning and organization. In these efforts the student can learn that design involves the overall process from recognition of the problem to its final disposition. He will learn that it includes:

- Necessary research to provide missing knowledge
- Synthesis of possible solutions
- Analysis of the possibilities to optimize the results

He should learn that environmental restrictions as to allowable noise and exhaust emissions may limit the number of design options available, and that cost, not technical elegance, is most often the "driver" in determining the final solution to a problem.

While weight is still of fundamental importance in airplane design, trade studies today tend to go beyond simple weight considerations. Alternatives are often evaluated in terms of direct operating costs and even in terms of estimated return on investment. These studies tend to be considerably more complex than those used earlier, and involve close coordination with cost analysts and other personnel who are outside the engineering department. The young engineer must learn that in practice the separate sub-tasks that need to be accomplished will involve people of varying skills and abilities, and that teamwork and communication are vital to getting the job done.

COMMUNICATION

The best young engineering graduates I know are above average in their ability to communicate, both orally and in writing. Not only do they express themselves well, but they have a knack for asking questions which elicit needed information from others. One of the hardest things a new engineer must learn is how to find out things he must know to do his job. Much time has been wasted because an engineer made a wrong assumption, when the correct data was readily available had he only asked. "Find out - don't assume" is an excellent rule for engineers of any age.

One of the areas in which young engineers are traditionally weak is writing, including spelling, grammar, and writing style. Supervisors spend an inordinate amount of time improving engineer's technical reports. The most common mistake a young engineer makes in writing a technical report is assuming that the reader knows as much about the subject as the writer does. This is seldom true, and frankly, rarely does the reader want to know as much about it as the writer does. In writing a report, the writer should consider first what the information is going to be used for and who will be using it. A report must be organized to make it easy for the reader - not for the writer. Generally the reader wants to be able to assimilate the few really important conclusions of the work and does not have time to understand every little detail.

The ability to communicate well is also fundamental to the job of continuous learning which is characteristic of the engineering profession. All of us know a few outstanding individuals who are able to rapidly identify the roots of almost any engineering problem by asking a series of well formed questions, even when the problem may be outside their own specialty. They have learned the art of communication which, when combined with a broad appreciation of engineering fundamentals, makes them outstanding contributors to their profession.

PROFESSIONALISM

Our best young engineers exhibit the characteristics of true professionals. They are responsible, thoughtful individuals who are proud of their role as engineers. In addition to being superior engineers, they also do not easily tolerate inferiority in other aspects of life. Today's engineering graduates are more aware of and concerned about moral, social, environmental and political issues than in the past, and are more willing to get personally involved in these issues than were their predecessors. I suggest that the ECPD Canon of Ethics for Engineers be made required reading for all senior engineering students. It will help furnish a baseline for the student by providing a good interpretation of the high standard of personal integrity that is required of a professional engineer.

Change in engineering is inevitable. By this I mean that nearly every engineer will at some time be asked to pull up stakes and move to another location. He will be asked to change his field of endeavor. He may be asked to drop a project overnight that he has worked on for several years and to start a new project. He will be required to learn new techniques, and to work with new people and in new environments. Constant change requires continuous learning. Change is inevitable to everyone and provides a particular challenge in our profession rarely equaled in any other. Our most promising young engineers look forward to this adventure.

CONCLUDING REMARKS

I believe that we have left the most important aspect of this Conference - students - to the last. Today's students will determine "The Future of Aeronautics", as this Conference is titled. Students should be an important element in the research triad formed by government, industry and academia. After all, the primary output of our technical universities is trained engineers, not research. Industry makes far more use of the former than of the latter, because engineers are more necessary than university research in getting our job done. Development of new technology alone is not what has made this country's aircraft industry the most successful in the world; it is our ability to apply new technology to create new products that is significant. Continuous interchange of ideas between government, universities, and industry will help assure that new graduates will have the necessary capabilities to be real contributors to the future growth of aeronautics in the United States.

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SUMMARY OF PANEL ON CURRICULUM FOR MODERN AERONAUTICS

By David L. Kohlman
The University of Kansas

Panel Chairman

Speakers:	Panel Members:
Leonard Roberts	Alfred Cronk
Eugene Covert	Garvin Von Eschen
Richard Holloway	Joseph Schetz
	Robert Pitts
	Bruce Reese

Although few of the speakers dealt with the details of which specific courses were needed, there was general agreement on the characteristics of a good curriculum and the type of graduate it should produce.

A good balance between fundamentals and a familiarization with the current state-of-the-art of engineering are required. But an overriding consideration is that the student must be prepared for diversity.

Furthermore, it was quite obvious that the university can never consider their graduates to be finished products. They have only been prepared to begin a lifetime of continuous learning. This fact has important implications for employers and professional societies such as the AIAA.

The instilling of professional attitudes is as important a function of a curriculum as the teaching of academic skills. And the prime ingredient in this process is the attitude of the faculty.

One of the primary concerns of aero engineering faculty today is not the detailed content of the curriculum, but its viability in the climate of today and the future. This concern was expressed in this and earlier sessions.

Unfortunately, little positive reinforcement was forthcoming from industry and NASA representatives. Dr. Robert's comments were typical as he expressed a need only for bright, intelligent graduates, well founded in fundamentals. He stated that little, if any, specialization was required to be a good aeronautical engineer.

Nevertheless, several professors on the panel articulated a feeling that the aerospace industry should provide special support and preference to aero departments and graduates because they are uniquely trained to handle the complex problems of the aerospace industry which cross many disciplines. This support is particularly needed because aero graduates are discriminated against by most other industries, in spite of the fact that the typical aero curriculum probably is a better vehicle for training students in basic problem solving skills in a variety of disciplines than most other engineering curricula.

SUMMARY OF SESSION III

A FORUM ON THE ROLE OF THE UNIVERSITY IN AERONAUTICS

PANEL DISCUSSIONS

By Laurence K. Loftin, Jr.
NASA Langley Research Center

INTRODUCTION

The first day's session consisted in the presentation of a number of invited papers prepared by well-known individuals from NASA, industry, and the academic community. The papers were thought provoking, raised many questions and issues, offered some solutions, and excited much discussion on the part of the audience.

The aviation industry was described as being healthy with a bright future. The market for new civil and military aircraft in the next 15 to 20 years was shown to be very large. Highly challenging technical problems in such areas as fuel conservation, environmental protection, new aircraft concepts, and airport and airway improvements were discussed; recent technology advancements and future prospects were also described. In the light of these discussions, an increasing need for young aeronautical engineering graduates to fulfill the requirements of industry in the coming years was predicted.

Yet, in spite of the large future opportunities in the aviation industry, enrollments in aeronautical engineering have decreased alarmingly in recent years, and based on present trends, the supply of new engineers will not meet future demands. For example, enrollments in aeronautical engineering departments have decreased by 50 to 70 percent as compared to the levels of the late 1960's. These reductions are two to three times larger than those experienced by engineering departments as a whole. The reasons for the decline of interest in aeronautical engineering as a career are many. The large layoffs of engineers by the aerospace industry in the 1970 time period no doubt raised many questions about the stability of a career in aerospace engineering. A feeling on the part of many students that advanced technology and engineering are somehow responsible for many of the social, environmental, and economic problems of the nation was also mentioned. In any event, there was a feeling that a need exists to sell the challenge and opportunities of aeronautical engineering to prospective college students.

Within the aerospace engineering departments themselves, a number of problems were discussed. The reduced amounts of grant and contract money was the subject of much debate, as was the relatively close control now exercised by the contracting agency over the directions in which university research must be channeled. Aging equipment and the need for modernization of research apparatus was also discussed. A deterioration in the scope and number of interrelationships between industry, government, and the universities came in for a great deal of discussion and a number of suggestions were offered. Finally, the question of whether there are too many aerospace engineering departments in the country was raised, and the problem of justifying such departments in view of the enrollment trends of recent years was indicated.

The papers and discussions of the first day provided the framework and tone for the panel discussions wich took place on the second day. The panels were made up of government, industry, and university personnel as indicated by the table of contents of this volume. Some of the panel members were asked to present prepared comments whereas others spoke extemporaneously. Audience participation following the formal panel discussions was extensive in all cases.

The topic of discussion by each panel together with some key questions and issues were:

I. University/Governments/Industry Relations

Questions and Issues:

Are they satisfactory?

How can they be improved?

How closely should sponsored university research be coupled with government and industry selected goals and programs?

What are the benefits of cooperative research between universities and government laboratories?

II. University Research in Aeronautics

Questions and Issues:

What kinds of work in aeronautics should universities do for government and industry?

To what extent should universities undertake applications and hardware oriented tasks, as opposed to the pursuit of more basic tasks?

What is the role of universities in developing new directions for aeronautics?

III. Curriculum for Modern Aeronautics

Questions and Issues:

What kinds of students should be developed through aeronautical engineering education?

To what extent should aerospace engineers be prepared for diversity and change?

To what extent should theory be emphasized, as opposed to practical engineering and design?

PANEL DISCUSSIONS

A brief summary will now be presented of what appear to be the most significant points developed by each panel.

Panel I - University/Government/Industry Relations

The broad question of whether satisfactory relations exist between university, government, and industry was touched on briefly by a number of individuals. The answers varied from "satisfactory but could be improved" to "the worst that they have ever been." There appeared to be a large consensus that the present conference was an important step in improving these relationships and that such conferences should be held on some type of regular basis. In this connection, it was pointed out that the last NASA-University Conference was held more than 10 years ago.

In more specific terms, the major part of the discussions of Panel I can be related to the following three topics:

1. Research grants and contracts

2. Exchange of personnel between university, government, and industry

3. The attraction of young students to aerospace engineering

Research grants and contracts. - The subject of research grants and contracts probably received more attention during the 2-day meeting than any other single topic. The importance of the subject was highlighted by one industry representative who stated that the majority of our knowledge dealing with the fundamental processes in aeronautics has come from university research and will continue to come from that source in the future. The need for an adequate supply of university grant and contract money on a consistent year by year basis to insure a continuing flow of basic research information was repeatedly stressed by both industry and university people. The manner of allocation and administration of grants and contracts was also discussed at length. The need to allow flexibility in the choice, direction, and emphasis in university research was emphasized and the frequently encountered necessity to show relevance to short-term objectives of individual program offices or researchers in the field was severely criticized. There was a strong feeling that the allocation of grants and contracts should be divorced, in large measure, from goal oriented NASA program offices located at both Headquarters and field installations and that such activities should be administered by a special office in Headquarters. The old "Office of Research Grants and Contracts" as constituted in NASA Headquarters during the early and mid 1960's was mentioned as an ideal method of operation.

Personnel interchange. - The interchange of personnel between university, industry, and government was described as extremely beneficial to all parties concerned. Such interchange offers the opportunity for faculty members to keep abreast of current technologies and problems, allows "retreading" of industry and government engineers, and permits students to obtain an understanding of the "real world" of engineering. The extent of such interchange, however, has appeared to decrease in recent years. A strong plea was made for the development of routine methods for implementing the easy interchange of university, industry, and government personnel. In this connection, a need was expressed for some new concept of institute which facilitates the mutual working together of university, government, and industry personnel as contrasted to the always difficult one-to-one exchange type of activity. Several innovative arrangements involving cooperative activities between NASA and university personnel were described. Institutes have been established at one NASA Center which are jointly operated by a university and the NASA. University students and faculty work together with NASA personnel on various research programs, and university faculty provide classroom instruction for both NASA and university students. In another arrangement, two senior officials from an NASA Center have been made consulting professors at a nearby university. The NASA/ASEE summer study program was also mentioned. Some attempts to effect an exchange of personnel between NASA and industry were also indicated although these activities have not been as successful as the NASA/university relationships.

The industry and government were described as having been very generous in allowing equipment to be used by university personnel. The need for new facilities and equipment in the universities was emphasized, however, and a plea was made that the universities be given first chance at equipment being discarded by government and industry.

Student enrollment. - The attraction of young students to aerospace engineering was the subject of a good deal of discussion. The primary conclusion of the discussion seemed to be that industry, university, and government all needed to do a better public relations job in selling the opportunities and challenges of aerospace engineering at the high-school level. Many approaches, such as news letters, personnel visits, etc., were described.

Panel II - University Research in Aeronautics

University research in aeronautics was the broad subject of the discussion of Panel II, and as evidenced by the first day's session and the Panel I discussion, was of great interest to all the participants. Many of the points raised in Panel I were discussed again in Panel II. For example, the need for freedom from a need to show relevance in order to obtain research support was again stressed and the importance of having someone other than a program manager make the grant decisions was emphasized. The succinct statement was made by one participant that " ... if you do honest, deep, conscientious research in a certain direction, not all directions, usually before you know it, it will be not only relevant but important." A need was expressed to be informed of problems by government and industry - not to be told what to do on a planned time scale. The desirability of consistent, long-term funding of grants and contracts was again emphasized.

Appropriate university research. - The types of research which can successfully be undertaken by universities were discussed by several participants. Theoretical investigations and studies, small-scale experimental work including systematic studies, small component design and development activities, some limited types of flight research, and state-of-the-art surveys were among the many types of programs mentioned as appropriate for a university to undertake. Some idea of the magnitude of a suitable university research program is perhaps given by one expressed view that the time constant of the program should be compatible with that of a Ph.D. thesis handled by a group of one or two faculty and assisting students. The view was expressed that there was absolutely no change in the number and challenge of unsolved problems in aeronautics which could be successfully undertaken by universities. A list of very specific problems related to one segment of the aviation industry was presented by one participant. The desirability of a certain number of joint programs with industry and government was also pointed out. There was a consensus that the construction and operation of large test facilities, the design and construction of large-scale aeronautical systems, and large interdisciplinary projects were not appropriate activities for universities to undertake.

The importance of university research in providing essential new knowledge in aeronautics was emphasized in the Panel I discussions. The importance of university research as an essential element of teaching was stressed in the Panel II discussions. Research provides contact with the real world and inspiration for both faculty and students.

Need for a national plan. - The lack of a national plan in aeronautics was suggested by one individual as an important contributing factor in the present problems of the aerospace industry and the universities. The existence of such a plan would assist in recruiting and would also provide long-range objectives which would provide assistance in formulating long-range research programs and obtaining financial support for such programs. NASA was suggested as the proper organization to prepare a long-range national plan in aeronautics. An NASA official indicated that such a plan was no doubt desirable but felt that NASA could not alone formulate such a plan but that a joint effort with DOT and DOD would be required.

Panel III - Curriculum for Modern Aeronautics

Attributes of aerospace graduates. - The discussions of Panel III centered around the attributes and qualifications desired of aerospace graduates and the training and curriculum of these graduates. The ability to learn, to solve problems, and to communicate effectively were among the important attributes mentioned as desirable in the aerospace graduate. The ability to write clearly and quickly was emphasized as was an understanding of the basic approach to problem solving involving several disciplines, that is, an understanding of design synthesis. The importance of being able to provide a 95-percent answer in 2 hours rather than 100-percent answer in 2 days was pointed out, as was the need to understand that, in the real world, most problems have more than one answer. Everyone agreed that the aerospace graduate should be prepared for diversity and change, that the faculty should prepare them for it, and that most graduates welcomed the prospect of variety in their professional careers.

Qualifications of aerospace graduates. - Desirable technical qualifications of aerospace graduates were discussed in detail. A good background in the basic disciplines was stressed. Physics, applied mathematics, continuum mechanics, and chemistry were obviously high on the list of important and necessary disciplines. The need to understand the use of such practical tools and methods as modern computers, design synthesis, and perhaps even drafting was pointed out. The desirability of the graduate having some knowledge in specialities such as aerodynamics and aircraft structures was indicated, although there was a general feeling that emphasis on specialities should be avoided at the undergraduate level.

Training of aerospace students. - An interesting comment on the training of engineers was to the effect that it is not possible to teach anyone to be a professional engineer within any formal course of study in any college or university. A B.S. graduate should be prepared to begin job training, and in the next 3 to 7 years, will become a professional. A proper mix of goal and discipline oriented courses was emphasized. The study of several disciplines as focused on the goal of understanding the design of an airplane was cited as an example of such a mixture. The study of the disciplines in an unrelated fashion tends to be sterile. Preliminary design courses were indicated to be an excellent means for integrating disciplines. As much laboratory work as possible was recommended in order to provide the student with some feeling for the real world of engineering.

A need for new textbooks for use by the aerospace departments was mentioned. Not only are present textbooks old but are the subject of justified complaints, particularly with regard to cost, by students. There apparently is going to be an AIAA committee formed to study a recent suggestion that AIAA become involved in the preparation of modern textbooks on various aspects of aerospace engineering.

Degree programs. - Specialization, types of degree programs, and design versus research were discussed. An interesting presentation was made in Panel II which was particularly appropriate to the subjects discussed in Panel III. A system of parallel graduate degree programs at the University of Kansas was described. In these programs a student may obtain M.S. and Ph.D. degrees by the traditional path of satisfactorily completing the required original research projects, or he may obtain Master and Doctor of Engineering degrees by following a design and systems oriented approach involving a team lead design and development project instead of a dissertation. The team is composed of students and is under student supervision. Faculty members participate as advisors. Graduates of this program were said to be in great demand. There was a great deal of discussion of the approach taken at the University of Kansas that offers the Doctor of Engineering degree. One body of opinion felt that doctor's degrees should be granted only on the basis of original research investigations, whereas others thought the design and systems approach was good and granting of the Doctor of Engineering degree was appropriate.

Finally, there was a good deal of discussion of the demand for graduates with aerospace degrees as compared with those having other types of engineering degrees. A need was expressed to advertise the capabilities of aerospace departments in the universities and their graduates to the industry and the government.

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